Going the Distance: The Impact of Distance to Market on Smallholders Crop and Technology Choices

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ABSTRACT

Smallholder farmers in Honduras and the Trifinio region of Central America contend with poor roads and high transportation costs when making production decisions. Farmers select crop activities based on cost, revenue and profit but are constrained by labor requirements, cash requirements, food security concerns, and input and output market access. Market access is directly related to distance to market. Distance to market increases the cost of inputs, increases transportation costs, and reduces the effective price farmers receive for outputs. We conduct two analyses to study the impact of distance to market on crop and technology choices. We utilize a household survey to analyze the determinants of fruit and vegetable production and market participation. Probit and multinomial logit models are employed to analyze the impact of distance to market and other variables on fruit and vegetable production. Results indicate that as distance to market increases, the probability of fruit and vegetable production for consumption increases and the probability of fruit and vegetable production for sale at market decreases.

In a second paper, we utilize data from extension agencies, research institutions, a household survey, and expert opinions to model a representative Honduran farm. With linear programming, we analyze the crop and technology mix selected by the farm given changes in distance to the output market, changes in distance to the input market, food security concerns, and labor market participation. We focus specifically on integrated pest management (IPM) technologies. Results indicate that beyond a specific distance, vegetable production ceases, while staple crop production remains profitable. Additionally, a combination of low, medium, and high-technology crop activities is selected by a profit-maximizing farm. Even far away from the market, medium and high-technology crop activities are selected. Overall, these two studies indicate that distance to market is negatively related to fruit and vegetable production. A reduction in transportation costs and an increase in the prevalence of less input-intensive integrated pest management techniques may increase the incidence of fruit and vegetable production and market participation in Trifinio and Honduras.

DEDICATION

I dedicate my thesis to my parents, Gregg Buckmaster and Sandy Weems Jones, to my sister, Michelle Buckmaster, and to my brother, Tommy Buckmaster. Thank you for all of your support and encouragement over the past two years.

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CHAPTER 1: INTRODUCTION

Every day farm households make decisions that impact their livelihoods. Farms in the developing world are typically small and the households are particularly poor. Smallholders must make purchasing and consumption decisions, as well as production and marketing decisions regarding their farms. Choices include which crops to produce, which crops to sell, which crops to consume, how much livestock to raise, what food products to buy, what inputs to use, whether to work on or off the farm or both, as well as many more. When making important decisions, smallholders take into account a variety of factors, including but not limited to production costs, transportation costs, risk, revenue, prices, wage rates, and food security concerns. Transportation costs are especially relevant for farmers in developing countries, as they often have fewer roads on which to travel, and if they have paved roads at all, they are regularly in poor condition. In addition to bad roads, many smallholders are located far from central cities or towns and thus face even higher transportation costs. For these farmers to participate in input and output markets, the cost of obtaining inputs or selling output cannot exceed the benefits. In some cases, farms may be so far from a market that it is prohibitively expensive for them to sell any agricultural products or purchase specific inputs, and therefore participate in subsistence farming only.

The introduction of integrated pest management (IPM) in developing countries may influence farmers' production decisions. IPM is a management strategy that combines pest biology, technology, and environmental information to reduce pest damage to the lowest economically viable level while protecting environmental and agricultural resources (National Road Map for Integrated Pest Management, 2004). Generally, IPM strategies reduce the amount of inputs utilized in production (especially pesticides, herbicides and fungicides) and therefore IPM may also reduce farmers' reliance on input markets. Farmers that are located far from markets but can adopt IPM technologies and practices may be able to overcome distance to market as a constraint to high-value fruit and vegetable production.

This research is based in large part on Johann von Thünen's model of agricultural land use. His theory states that agricultural goods will be produced at varying distances from the central city based on how expensive they are to transport. Goods that are cheap to transport, like staple crops, will be produced relatively farther from the central city than will goods that are expensive to transport, such as fruits and vegetables. Thünen also points out that there will be a distance beyond which no agricultural production takes place. We hypothesize that this theory will hold true for Honduran farmers- that is, farmers relatively close to the central city or market will produce fruits and vegetables while farmers relatively far away will produce staple crops such as maize and beans. In addition to impacting crop choice, distance from the central city also impacts the use and cost of inputs. Inputs are relatively more expensive for the farm the farther it is from the market- the cost of obtaining the input is higher.

This study has two interconnected but distinct parts- an econometric analysis utilizing a household survey and a linear programming model of a representative farm household utilizing production budget data. Both analyses utilize data from the same geographic region- Central America. The survey used in the econometric analysis is of households in the Trifinio region of Central America, which includes parts of Honduras, Guatemala and El Salvador. The data for the linear programming analysis are from extension and research agencies that work with Honduran farms. Transportation infrastructure is particularly poor in this region, making market access difficult for many. The literature on the relationship between market access and farmers production decisions is thin, as is the literature on the relationship between market access and technology adoption. Our analyses seek to contribute to these larger bodies of literature. We first present the econometric analysis of the Trifinio household survey- detailing the justification for our analysis, the model specification, results, and conclusions. We then move on to the linear programming model- outlining the model's basic form, running a baseline model and several scenarios, and drawing conclusions about the results.

CHAPTER II: DETERMINANTS OF FRUIT AND VEGETABLE PRODUCTION BY SMALLHOLDERS: EVIDENCE FROM THE TRIFINIO REGION OF CENTRAL AMERICA

II.1 Introduction

The Trifinio region of Central America is the geographic area where the borders of Honduras, Guatemala and El Salvador meet (Comisión Trinacional del Plan Trifinio, hereafter CTPT, 2009). In 1998, the three countries came together to create Trifinio, a region with "financial, administrative and technical autonomy" led by the Plan Trifinio Tri-national Commission (World Bank, 2010). This mountainous region is characterized by high levels of rural poverty (despite concerted efforts to increase development), a wealth of natural resources, and the presence of several important tourist attractions. The Trifinio governing body reported in 2004 that the "majority of the population has no choice but to develop subsistence activities on the slopes", severely limiting income (CTPT, 2004). The predominance of small farms in the region (typically less than 7 manzanas) further "limits the possibility that farming is profitable" for small producers and their families (CTPT, 2004).

Farmers in Trifinio make production decisions based on household needs and income goals. Farmers working solely for subsistence purposes must determine which crops they need to produce for consumption and in what quantities to produce each crop. Crop mix may vary depending on food security concerns, input costs, labor requirements, and soil and climate conditions. Farms producing crops for both consumption and sales face additional concerns, including input and output market access, transportation costs, and expected profit. The majority of farms in Trifinio are semi-commercial. The crop mix decision for these farms can be distilled into two broad choices: production of staples (maize, for example) and production of perishables (fruits and vegetables). Because these two types of crops require different production and marketing practices, smallholders may focus their semi-commercial efforts on one type or the other.

Perishable crop marketing can be more costly than staples marketing, due to the time sensitive nature of most fruits and vegetables as well as their limited capacity to withstand transportation over difficult terrain. Marketing costs are high in Trifinio due to a lack of paved roads and limited personal vehicle ownership. If costs of market participation exceed the net revenue from high-value fruit and vegetable production and sales, rural farmers will forgo the potential income from high-value fruits and vegetables in favor of more reliable income from staple crops. If marketing costs can be reduced enough to make participation in high-value fruit and vegetable markets profitable, farmers can improve their incomes and welfare by switching some of their land from the production of staple crops to that of high-value fruits and vegetables.

The objective of this study is to identify the determinants of fruit and vegetable production in the Trifinio region and to identify differences between households that produce and consume fruits and vegetables and households that produce and sell fruits and vegetables in the market. Specifically, we are interested in ascertaining what effect, if any, distance to market has on the decision to produce and/or sell fruits and vegetables. We aim to answer this question: Are households farther from the market less likely to produce fruits and vegetables in general, or are they only less like to participate in fruit and vegetable output markets? In addition to distance to market, there are other factors that influence crop decisions, and we look into how these factors differ for households that participate in fruit and vegetable output markets and households that do not. Using data from a 2007 survey of Trifinio households, we estimate a probit model of fruit and vegetable production, and subsequently estimate probit models of fruit and vegetable autarky and fruit and vegetable market participation. Lastly we estimate a multinomial logit model and examine the choice between three outcomes: no fruit and vegetable production, fruit and vegetable production for consumption, and fruit and vegetable production for sale in the market. We look at a variety of possible determinants, including travel time to a main road, rainfall, altitude, total manzanas farmed, irrigation, the age of the head of the household and others. We find that distance to a main road is positively related to fruit and vegetable autarky and negatively related to fruit and vegetable market participation. Additionally, we find that the age of the head of the household, irrigation, and the amount of land farmed are significant determinants of fruit and vegetable production. This paper begins with background on the Trifinio region of Central America, followed by a review of literature on market participation, distance to market, and crop choice. Next we present a conceptual framework which guides our data and methods selection. A section detailing the data used for our analysis follows. We then lay out the empirical model and report the results of the analysis. Finally, we summarize the results and conclude the paper.

II.2 Background

Trifinio is an autonomous region in Central America made up of portions of Honduras, Guatemala and El Salvador. Since 1998, the Plan Trifinio Tri-national Commission has worked to accomplish goals laid out in its Trifinio Plan. Two broad goals are better management of traditionally marginal border lands and improvement in the economic potential of the area (World Bank 2010). Objectives of the commission include improvement in both the level of income and the life of the people in the area, improvement in the area's physical infrastructure, economic growth, and social development (CTPT 2009).

At approximately 7,367 square kilometers, with a population of about 700,000, Trifinio contains a substantial portion of the total economic activity of Honduras, Guatemala, and El Salvador. The region possesses a wealth of natural resources including water resources and a biologically diverse environment (CTPT 2009). Two of the major watersheds in Central America, the Lempa River and the Motagua River, are found in the mountainous Trifinio region (CTPT 2004).

Economic conditions in Honduras, Guatemala and El Salvador are similar. The agricultural sector of the three countries accounts for 12.4%, 13.3%, and 11% of gross domestic product (GDP), respectively (CIA May 2011). Significant percentages of the labor force in each of the three countries are working in agriculture (19% in El Salvador, 39.2% in Honduras, and 50% in Guatemala). Guatemala's farmers are particularly poor, as fifty percent of the population produces only 13.3% of the GDP. Notably, the percentage of the population living below the poverty line is high (65% in Honduras, 56.2% in Guatemala, and 37.8% in El Salvador) in all three countries, reflecting limited opportunities for people to improve their livelihoods (CIA May 2011). Unemployment in all three countries continues to be a serious impediment to development (USAID 2011).

An advantage of the Trifinio area is its relative proximity to major markets, specifically San Salvador, El Salvador; Copan, Honduras; and Esquipulas, Guatemala. These markets, in large part due to tourism, are places where Trifinio people can travel for work and where farmers can sell their products. Nevertheless, getting to these areas of economic activity can be difficult, as paved roads make up only about a third of the total kilometers of roadway in Guatemala and even less in Honduras and El Salvador (CIA May 2011). It is far more common to see dirt roads and trails in Trifinio than paved roads. The predominance of unpaved roads in the region contributes to limited access to markets, education, healthcare and other social services.

Despite Trifinio's three distinct nationalities, tri-national integration is possible due to the economic and geographic similarities. Trifinio policymakers work in the best interest of the region, but all of Honduras, Guatemala, and El Salvador stand to gain from increased development in this deeply impoverished area.

II.3 Previous Literature

Literature on the determinants of production of perishable crops as compared to the determinants of production of staple crops is limited. However, there is substantial literature on the determinants of market participation by agricultural households, as well as the impact of transportation costs on crop choice.

In one of the earlier studies on market participation, Goetz determined that high transactions costs are a major cause of failure to participate in markets (1992). He estimated both a single equation probit model and a bivariate probit model and in both models found that "improved market information increases the probability of participation by sellers" (1992, p.442). The age of the head of the household also had a significant impact on seller market participation in the single equation model. Many of the variables tested, such as equipment ownership and the total number of people in the household did not significantly affect sellers' decisions. In another study of market participation, Alene et al. looked at the "effects of transactions costs on marketed surplus and input use in Kenya" (2008, p.318). They found that output price does not affect entry into the output market; price only affects the quantity supplied (Alene et al. 2008, p. 318). Fluctuations in output price do not change a supplier's decisions to participate in the market, but increases in output price do increase the quantity sold. They also found that institutional transformations (e.g. group marketing) lower costs of access to market (2008, p.318). Institutions such as government and marketing boards are important in the development of the rural farming industry. Perhaps of most interest to this research is the finding that "while maize supply declines with distance to the maize market, both maize market participation and supply decline with distance to the fertilizer market" (Alene et al. 2008, p.325). As input markets get farther away, farmers decline to participate in the market at all, instead of just reducing supply as they do when the output market is farther away. In Kenya, fertilizer markets are less accessible than output markets and this can prevent market participation (Alene et al. 2008, p.325).

Fafchamps (1992) looked specifically at cash crops in the developing world and the reason why large-scale farmers tend to devote a greater share of their land to cash crop production than small-scale farmers. He found that many "Third World" farmers have to be self-sufficient, due to the thinness and isolation of rural food markets caused by a combination of high transport costs and low agricultural productivity (Fafchamps 1992). Fafchamps also notes that both investment in roads and transportation and the removal of trade-impeding institutions are essential to an environment with crop specialization. With results that also identify roads as an important factor in agricultural markets, Minten and Kyle establish transportation costs as the main reason for differences in food prices between producer regions (1999). In the spirit of von Thünen, they find that perishable products will be transported smaller distances than basic staples, and thus staples will be produced farther from markets than perishables (Minten and Kyle 1999). Minten and Kyle note that low-quality roads are twice as costly for transporting crops as paved roads. They write that road improvement not only "reduces transport costs and increases producer prices", but "increases the area where food is sold and…might induce changes in the type of food that is sold" (Minten and Kyle p.494).

Omamo analyzed relationships between farm diversification, market failure, and market access based on transactions costs and specialization (1998a, p.152). He concluded that when trade is expensive, production will in fact change based on how far away the farm is from points where trade can occur. Production technologies may not be used if they increase specialization to the point where transactions costs cause total costs to be higher than total revenue (Omamo 1998a, p.154). Despite cash crops' typically larger input costs, the higher returns from sale indicate that the cash crop should represent the majority of the farm plan (Omamo 1998a, p.155). He concluded that diversification is a positive and rational decision farm households make in order to gain comparative advantage and respond to prices (1998a, p.161). He also studied crop choices in Kenya and found similar results. Farmers, as a response to high transport costs, routinely produced more low-yield crops than cash crops (1998b, p.116). Crops that are both consumed and sold, like maize, are more directly impacted by transport costs then crops that are only sold, i.e. cotton (Omamo 1998b, p.121).

Key, Sadoulet, and de Janvry modeled the supply response of producers and their decisions to sell, buy, or not participate at all (2005, p.245). They concluded that "market participation depends on both fixed and proportional transactions costs (PTCs), while the supply decision, conditional on market participation, only depends on PTCs" (Key, Sadoulet, de Janvry 2005, p.251). Fixed transactions costs do not depend on the quantity of the good traded and include the cost of searching for a salesperson and the costs of bargaining. Proportional transactions costs depend on the quantity of the good traded; for example, fuel costs. Using data from Mexico, the authors found that the factors that increase production by sellers are: the use of high-yielding corn, high levels of mechanization, high access to credit, and higher farm-gate prices (Key, Sadoulet, de Janvry 2005, p.255). Results suggest that improving transportation and marketing organizations will lower transactions costs significantly, to the point of increasing both market participation and production levels (Key, Sadoulet, de Janvry 2005, p.258). Government involvement and better business strategies in tandem can improve the marketing environment for Mexican farmers.

Minten, Stifel and Dorosh produced a paper examining transactions costs in Madagascar, coming to three conclusions. First, poverty increases with an area's remoteness; second, yields of major crops decrease with remoteness; and third, the intensity of input-use decreases with remoteness (2003, p.3). Looking specifically at rice, "halving travel time per kilometer on major highways" and feeder roads "will increase primary season rice production by 1.3" and 1.0 percent, respectively. (Stifel, Minten, and Dorosh 2003, p.3). They measure isolation by the time it takes to travel to an urban center, cost of transporting rice, and a remoteness index. The authors note that an area's distance from a market cannot be changed, but the quality of the roads getting people to and from markets can be changed and improved. The overall positive effect of higher quality roads is emphasized in the study.

Escobal studied infrastructure and markets in Peru, pointing out that when infrastructure investment is made in isolation it is subject to diminishing returns, but these returns can be overcome if investments are combined effectively (2005). Joshi, Joshi and Birthal find that constraints to vegetable production faced by smallholders include a lack of assured markets and a lack of an efficient marketing system which then leads to large crop losses (Joshi, Joshi and Birthal 2006). They find that vegetable production can result in low marketable surplus that increases transactions costs for smallholders (2006). As a potential solution to the barriers faced by smallholders, the authors suggest strengthening farm-firm linkages through arrangements such as contract farming (2006).

More studies exist on market participation and transportation costs based on data from Africa than Latin America. Obare, Omamo and Williams found that in Kenya high transportation costs lead farmers to use less land for production, less fertilizer and less machinery. Additionally, "higher access costs are also associated with more land devoted to maize, the region's, Kenya's, and Africa's major staple food crop" (Obare, Omamo, and Williams 1998, p. 253). Their work supports the idea that market access impacts crop choice between perishables and staple crops. Renkow, Hallstrom and Karanja used a survey from Kenya to determine how much "fixed transactions costs" cost agricultural households producing maize. They conclude that as economic isolation increases, the size of transactions costs increases and further state that fixed transactions costs are equivalent to an ad valorem tax of 15% for their households (Renkow, Hallstrom, and Williams 2004). Of particular interest here is the additional support for the inverse relationship between transactions costs and market participation by agricultural households. In a paper studying the Democratic Republic of Congo, Ulimwengu specifically points out the impact of a reduction in transportation costs on perishable crop marketing, asserting that lower transportation costs lead to an increase in the profitability of perishable items relative to non-perishable crops. Furthermore, Ulimwengu asserts that better roads can reduce the costs of inputs in such a way that increases "the scope of profitable trade…This in turn should raise rural income, lower food prices, reduce spatial disparity in food prices, and reduce dependence on food imports" (p. 3-4). Komarek (2010) conducted a study that parallels the objectives of this study. In the paper, Komarek examines the determinants of commercialization in banana markets in Uganda using a household survey. He found that higher prices and higher yields encourage market participation while “geographical remoteness” (proxied by distance to market) reduces likelihood of market participation. Komarek concludes that investment in rural roads by the government could benefit agricultural households (2010).

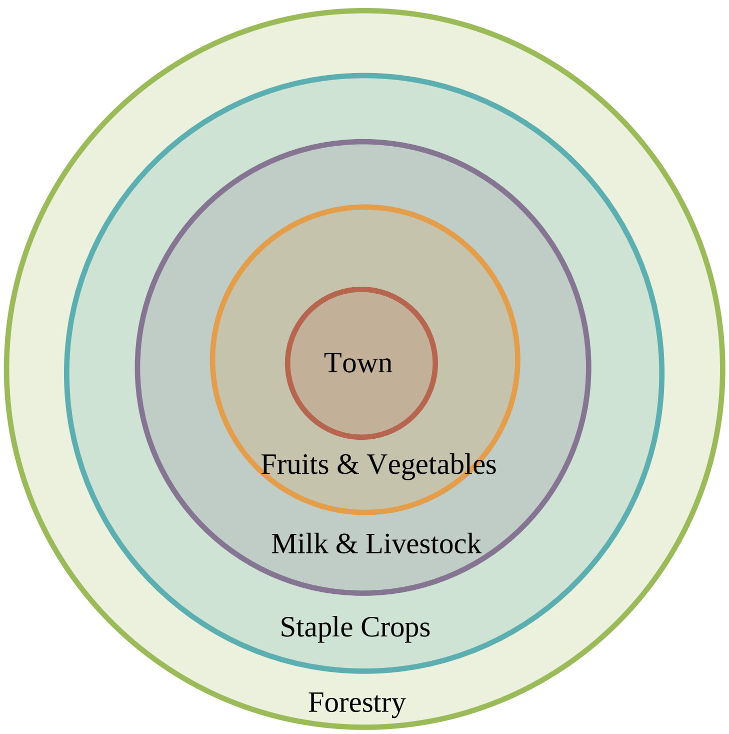
The preceding literature review leads us to several conclusions. Firstly, distance to market is an important factor for agricultural households. Often, distance to market is negatively correlated with market participation; that is, as distance to the market increases, market participation declines. Additionally, most of the previous literature agrees that improvements in roads and infrastructure can effectively reduce distance to market (as measured by travel time) and in effect improve the likelihood of market participation. Previous studies also support the claim that isolation from markets affects the crop mix decision, specifically the decision between staple crops and perishable crops. Several studies assert that the more isolated an agricultural household is, the more likely it is to elect to produce staple crops over perishable crops. These conclusions set the foundation for our study, and lead us to our central hypothesis that as distance to market increases, the probability that an agricultural household produces perishable crops decreases.

II.4 Conceptual Framework

The theoretical approach for this study combines two broad economic theories: 1.) Johann von Thünen’s model of agricultural land use (Thünen 1966) and 2.) The agricultural household model first developed by Singh, Squire and Strauss (1986). Von Thünen’s theory discusses the role of distance in determining the location of different types of agricultural production. Singh, Squire and Strauss developed a model of utility maximization for semi-commercial farm households, which are the types of households of concern in this study.

In his work *The Isolated State*, Von Thünen asserts that goods that are either heavy or expensive to transport will be produced closer to the center of the area (the majority of economic activity is assumed to be located at the center) and goods that are cheaper to transport will be produced farther from the center. Perishable fruits and vegetables fall into the first category as they are expensive and heavy to transport, while staple crops like maize and beans are less expensive to transport. A model of concentric rings emerges out of Von Thünen's work that describes the expected pattern of cultivation in an area.

Figure 2.1: A visual representation of Von Thünen's concentric rings



At the center of the rings is the town, and in the ring closest to the town fruit and vegetable gardening takes place. Milk and livestock production is located in the next ring followed by the production of staple crops. Farther beyond these agricultural activities are the rings representing forestry and marginal land not used for any type of agricultural production. Von Thünen's theory includes many assumptions, including that all properties are managed rationally and that soil fertility is constant on all farms. While these and other assumptions may be difficult to accept outside of the "isolated state", the underlying concept prevails. As additional towns, rivers, and roads are introduced in an area, rings form around these features and there can be many different places where fruit and vegetable production occurs. Because waterways and roads reduce transportation time, transportation costs of products produced near these features are lower. Consequently, fruit and vegetable production is possible far from a market if it is near a waterway or road.

Singh, Squire and Strauss developed an agricultural household model in which the household is described as semi-commercial; that is, some of what is produced is consumed and some is sold. The basic model of is of a household that maximizes utility, subject to a cash income constraint, a time constraint, and a production constraint. Labor for agricultural production includes family labor and hired labor (Singh, Squire, and Strauss 1986). Family members can also work off the farm if there is an opportunity for competitive wages. These households must decide what types of activities to engage in: for example, the production of basic staples, cash crops, fruits and vegetables, the raising of livestock. In addition to the activity the household must decide whether the product will be consumed or sold as surplus in the market. The decision to produce and sell a surplus depends on several factors, including the existence of a market for the product, transportation costs, price received, and access to inputs for larger-scale production. A major contribution of the agricultural household model is the "profit effect"- the "one way relationship between production on one hand and consumption and labor on the other hand" (Singh, Squire, and Strauss 1986, p.7). Later in the paper we look at the impact of distance to market on the decision to produce fruits and vegetables for profit and produce fruits and vegetables for consumption.

Several testable hypotheses emerge from the literature and economic theory for this analysis. Firstly, as distance to market decreases for Trifinio households, the probability of fruit and vegetable production will increase. The closer a household is to the market, the lower transportations costs will be; this lower transportation cost in turn reduces the cost of producing high-value fruits and vegetables relative to the cost of producing staple crops. The probability of the sale of fruits and vegetables will be higher for households closer to markets as they face lower costs than households farther from the market. Secondly, as distance to market decreases, input usage will increase. Lastly, the decision between the production of perishable crops and the production of staple crops depends on the distance from the household to the market.

Factors such as the presence of a marketing organization, education level of the head of the household, and the size of the family living in the agricultural household are also possible determinants of fruit and vegetable production for Trifinio farms. We predict that, in conjunction with many other factors, distance to market is a significant determinant of fruit and vegetable production. We hypothesize that for Trifinio fruit and vegetable producers an increase in distance to market both reduces the likelihood of market participation and increases the likelihood of fruit and vegetable production for household consumption.

II.5 Data

II.5.1 Survey

Data are from the 2007 Survey of Living Conditions conducted by the International Food Policy Research Institute (IFPRI) in conjunction with the Plan Trifinio Tri-national Commission. Four hundred and ninety three households in the Trifinio region participated in the survey and answered questions about their household, education, economic activities, agricultural activities, consumption and several other categories. A shorter community survey was also conducted and contains information on markets, employment, banking, infrastructure, communication, agriculture, education, and other institutions. A copy of this questionnaire can be obtained from IFPRI.

II.5.2 Summary Statistics and Variable Description

Of the total households surveyed, 43% are located in Honduras, 45% in Guatemala, and about 12% in El Salvador. The households are from 6 different departments in the Trifinio region; Copán and Ocotepeque in Honduras, Chiquimula and Jutiapa in Guatemala, and Chalatenango and Santa Ana in El Salvador. About 73% are classified as rural and 33.47% produce agricultural products. One hundred and sixty five households are considered agricultural households and are included in the subsequent analysis; 57% of agricultural households in the sample are in Honduras, 36% in Guatemala, and 7% in El Salvador. Fifteen percent of the agricultural households are headed by females, and the average household size is 5.6 people.

Table 2.1: Summary Statistics

		All agricultural households		Households producing fruits and vegetables		Households not producing fruits and vegetables	
Variable	Description	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
fveg	=1 if hh produces fruits and/or vegetables	0.27	0.45	-	-	-	-
producefvegonly	=1 if hh produces fruits and/or vegetables but does not sell	0.17	0.38	-	-	-	-
prodandsoldfveg	=1 if hh produces and sells fruits and/or vegetables	0.10	0.30	-	-	-	-

timemainrd	Time from hh (household) to main road in minutes	45.64	53.31	51.73	60.30	43.36	50.52
rainfallmm	Average municipality rainfall in millimeters	1465.22	289.33	1530.07	193.97	1440.91	315.08
altitude	hh altitude in meters	892.18	341.26	934.04	358.25	876.48	334.86
totalmzfarmed	Total manzanas farmed by hh	1.99	2.86	2.38	3.4	1.84	2.62
irrigate	=1 if hh uses irrigation	0.10	0.30	0.16	0.37	0.08	0.28
agehh	Age of the head of the household in years	48.6	15.76	48.67	16.72	48.58	15.46
agehh2	Age of the head of the household squared	2608.96	1666.63	2641.82	1805.16	2596.64	1619.45
Honduras	=1 of the household is located in Honduras	0.57	0.50	0.84	0.37	0.47	0.50
femalehh	=1 if the head of the household is female	0.15	0.36	0.16	0.37	0.15	0.36
numbworkers	Number of family members between ages 8 and 65	4.21	2.10	4.24	2.08	4.2	2.12
numbdependents	Number of family members younger than 8 and older than 65	1.39	1.23	1.49	1.22	1.35	1.24
producerorg	=1 if there is a producer organization in the hh's community	0.56	0.50	0.76	0.43	0.48	0.50
pavedaccessroad	=1 if the access road used by the hh is paved	0.11	0.31	0.09	0.29	0.12	0.32
# of Obs.		165		45		120	

The variables considered in this study are derived from IFPRI's household and community surveys and were selected based on the theories outlined above. Geographic, agricultural, household, and community variables are important for identifying the determinants of fruit and vegetable production and market participation.

The dummy variable *fveg* is equal to 1 if the household is producing any of the following crops: tomatoes, peppers, onion, cabbage, carrots, potatoes, yellow squash, pear squash, yuca, cucumber, avocado, citrus, watermelon, plantains, bananas, papaya, mango, pineapple, or plums. The two dummy variables *producefvegonly* and *prodandsoldfveg* are the variable *fveg* decomposed into two distinct groups. The variable *producefvegonly* takes on a value of 1 if the household is producing fruits and vegetables but did not report sales of those crops. Similarly, the variable *prodandsoldfveg* takes on a value of 1 when the household produces any of the aforementioned fruits and vegetables and sells some portion of them. Of much interest to this study is the variable *timemainrd*. Most households reported the time in minutes to the nearest main road but not the distance in kilometers. This may be indicative of limited personal vehicle use; if households do not use a personal vehicle that tracks distance, they may not know the precise distance in kilometers from their house to the main road. All 165 agricultural households reported time to the main road. For this reason, time in minutes to the main road is used as a proxy for market access instead of distance in kilometers to the main road. Time to the main road incorporates physical distance, road quality, and mode of transportation used, although the way the question is worded in the survey does not allow for these aspects to be decomposed for analysis. The average time to the main road for all 165 agricultural households is about 46 minutes.

The variables *rainfall*, *altitude*, and *rain_alt* are geographic characteristics of the household locations. The independent variable *rainfall* measures the average annual rainfall received at the municipal level, not the household level. The rainfall data comes from another study of the Trifinio region (Elias, 2008). The variable *altitude* is measured in meters at the household level; *rain_alt* is a variable interacting *rainfall* and *altitude*, an interaction of these two variables could be important in an analysis of these agricultural households. Two agricultural variables, *totalmzfarmed* and *irrigate*, measure the total manzanas of land used for crop production and irrigation use on the farm, respectively. The variable *irrigate* equals 1 if the agricultural household uses irrigation on any portion of its land. Age of the head of the household is labeled *agehh* and is also squared (*agehh2*) to study the impact of head of household age on fruit and vegetable production. A parabolic relationship between age of the household head and fruit and vegetable production is conceivable.

The majority of households producing fruits and vegetables are located in Honduras, and this variable (*honduras)* is included to account for unobserved factors that make fruit and vegetable production more likely to occur there. In the previous literature on agricultural households, gender of the head of the household is considered important to household decisions. In this study, the variable *femalehh* equals 1 if the head of the household is female. The proportion of female heads of household is consistent across the three groups in Table 2.1. Family composition is another possibly important factor in the decision of what crops to produce. The number of workers in the household (*numbworkers*) as compared to the number of dependents (*numbdependents*) can impact the types of food the household produces for consumption as well as the amount of family labor the household is able to provide. Workers are persons living in the household between the ages of 8 and 65, and persons younger than 8 and older than 65 are classified as dependents. The presence of a producer organization in the community is included in this analysis (*producerorg*) because we believe access to such organizations is positively related to fruit and vegetable production. From the table it is clear that membership in a producer organization in the community is more common among fruit and vegetable producers than fruit and vegetable non-producers. Lastly, the condition of the road could be important in the production decision, and while some of the road condition is captured in the *timemainrd* variable, we thought it pertinent to take a look at a distinct road quality variable that is equal to 1 if the households' main access road is paved (*pavedaccessroad*). Paved roads allow for faster input and output transportation, as well as reduce wear and tear on farm vehicles.

Table 2.2 displays summary statistics for two groups. From the variables *producefvegonly* and *prodandsoldfveg* we know that the proportion of the sample agricultural households producing fruits and vegetables is less than a third and the proportion of households selling fruits and vegetables is only about 10%.

Table 2.2: Summary Statistics -
Further Breakdown of Fruit and Vegetable Producers

	Fruit and Vegetable Sellers		Fruit and Vegetable Producers Only	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
timemainrd	28.41	31.16	65.89	69.28
rainfallmm	1494.12	162.21	1551.89	210.75
altitude	1046.29	418.13	865.89	304.63
totalmzfarmed	1.27	1.09	3.05	4.15
irrigate	0.35	0.49	0.04	0.19
agehh	44.94	9.65	50.93	19.66
agehh2	2107.29	821.81	2966.36	2149.64
Honduras	0.82	0.39	0.86	0.36
femalehh	0.12	0.33	0.18	0.39
numbworkers	4.71	1.53	3.96	2.33
numbdependents	1.29	1.31	1.61	1.17

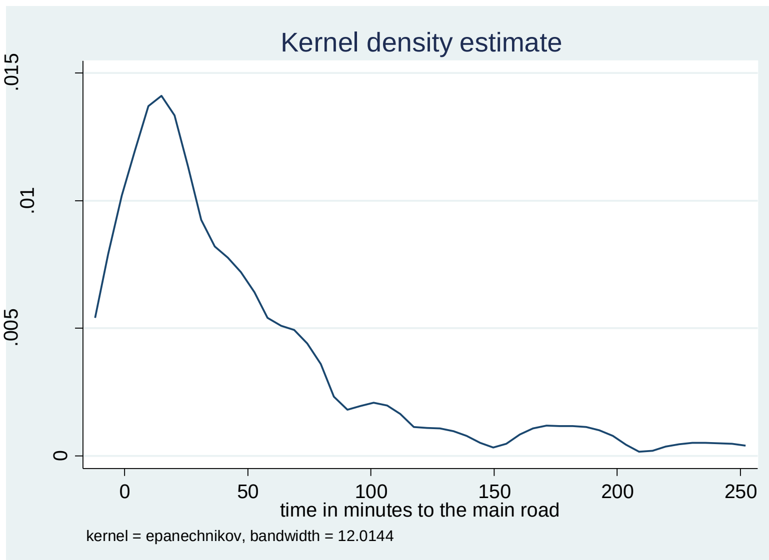
producerorg	0.71	0.47	0.79	0.42
pavedaccessroad	0.06	0.24	0.11	0.32
# of Obs.	17		28	

II.5.3 Descriptive Statistics

From the summary statistics, several interesting observations emerge. Of the 45 households producing fruits and vegetables (from the variable *fveg*), 84% are located in Honduras. While the majority of the households in the larger sample of 165 households are also located in Honduras (57%), there does seem to be a connection between producing fruits and vegetables and residing in Honduras. On average households producing fruits and vegetables benefit from higher rainfall amounts and are located at higher altitudes than households not producing fruits and vegetables. Additionally, households producing fruits and vegetables farm more total manzanas than their counterparts.

The variable *timemainrd* is highly skewed to the right, meaning there are relatively few high values of time to the main road in the sample (see Figure 2.2 below). The range of time to the main road is wide in the sample, from 0 minutes up to 240 minutes, or 4 hours. However, a mean of 46 minutes and the distribution indicate the majority of observations are clustered in the lower end of the range. From this we can assert that the majority of farmers are not located as far away from a main road as first expected, and that what is considered a “long way” from the main road may in fact be 1 hour for the majority of households (as opposed to 4 hours). While distance to the main road is not the same as distance to the market, this measurement gives insight into the relative level of isolation the two groups face. An average of 46 minutes away from the main road could imply that small changes in assets or infrastructure could have a large impact on a household's well-being- for example, acquisition of a vehicle that can traverse for an hour on an unpaved road could open up the possibility of commercialization to some of these agricultural households.

Figure 2.2: Kernel density estimate of *timemainrd*



A closer look at the differences between households that produce fruits and vegetables but do not sell and households that both produce and sell fruits and vegetables offers support for studying the two groups separately. There is a large difference in time to the main road between producers and sellers. It takes producers on average 66 minutes to reach the main road; while sellers have to travel only 28 minutes on average to the nearest road. An OLS regression of the independent variable *timemainrd* on the dependent variables *producefvegonly* and *prodandsoldfveg* shows that time to the main road is a statistically significant determinant of whether agricultural households produce fruits and vegetables for consumption or to be sold. Another difference in the two groups is the average age of the head of the household: for producers, it is 51 years old, and for sellers, 45 years old. Households selling fruits and vegetables seem to have slightly younger household heads. Both *agehh* and *agehh2* are significant when included in OLS regressions where *producefvegonly* and *prodandsoldfveg* are the dependent variables. The difference in the number of sellers and producers using irrigation is also large- 35% of sellers irrigate at least some of their farmland while merely 3.6% of producers only irrigate. A t-test shows that the variable *irrigate* is statistically significant for households that both produce and sell fruits and vegetables.

II.6 Empirical Model

Based on previous empirical studies (Goetz 1992; Alene et al. 2008) and the conceptual framework outlined above, we estimate the probability that an agricultural household produces fruits and vegetables for any purpose (consumption or sales) given the independent variables described above. The literature suggests that transactions and transportation costs impact production decisions for agricultural households, and distance to the market as measured by travel time is part of these costs. While time to the main road is expected to be important in determining participation in fruit and vegetable production, many other variables may impact this decision. The dependent variable in this model is binary: “1”, if the household produces fruits and vegetables and “0” if the household does not produce fruits and vegetables. For this type of dependent variable, a limited dependent variable model is useful (Wooldridge, 2009). In order to restrict the probability of fruit and vegetable production to a value between zero and one, a logit or probit model must be employed. We estimate a probit model of fruit and vegetable production, which can be given as:

$$Prob(fveg = 1|Z_p) = F(\beta_p' Z_p) + e\ ,\ \ e \sim N(0,1) \qquad \text{(Model 1)}$$

where $fveg$ takes a value of 1 if the household produced fruits and vegetables in the 12 months before the survey was administered in November and December of 2007; F is the cumulative distribution function of the standard normal distribution; Z_p is a vector of explanatory variables; β_p is a vector of parameters to be estimated; and e is a random error term with a standard normal distribution and zero conditional mean, that is, the average value of the error does not vary across the sample and the expected value of the error is zero. This type of model is estimated using maximum likelihood estimation (MLE), because ordinary least squares and weighted least squares methods are not useful when the model is nonlinear. Because MLE in this model is based on the distribution of *fveg* given the vector of independent variables Z_p, the heteroskedasticity in the variance of *fveg* $|Z_p$ is accounted for (Wooldridge, 2009). Under very general conditions, MLE is consistent, asymptotically normal, and asymptotically efficient (Wooldridge 2009). We will discuss later on in the analysis whether these assumptions hold for this dataset.

The vector of explanatory variables Z_p could include fourteen possible variables, selected based on previous literature, study objectives, and empirical evidence. However, not all fourteen variables are included in the subsequent analysis; some are highly correlated, and others do not add explanatory value to the regression. Also, our sample size is 165 households, which limits the number of independent variables we can appropriately include. In trying to avoid omitted variable bias and obtain unbiased coefficient estimates, we select a vector of independent variables we believe will result in efficient estimates while still explaining why some agricultural households participate in fruit and vegetable production and sales. Four of the variables included in Tables 2.1 and 2.2 are excluded from the probit analysis: *rain_alt, numbworkers, numbdependents*, and *pavedaccessroad*. The term *rain_alt*, interacting rainfall and altitude, is obviously highly correlated with both *rainfallmm* and *altitude*, but beyond that was not statistically or economically significant in any preliminary regressions. A household that is at a high altitude but receiving little rainfall does not appear to be any more likely to produce fruits and vegetables than a household that is at a high altitude and receiving a lot of rainfall.

In determining whether *pavedaccessroad* should be included in the analysis, we considered the high multicollinearity between *timemainrd* and *pavedaccessroad*. We believe by selecting the time to the main road in minutes over the physical distance to the main road, we are capturing the impact of a paved access road within the variable *timemainrd*. Physical distance in kilometers tells us nothing of the road quality, while time to the main road is directly a result of physical distance, road quality, and mode of transportation. Lastly, the variables *numbworkers* and *numbdependents* are excluded from the probit analysis for this study. The labor market in the Trifinio region allows agricultural households to hire in labor to help with agricultural production. Therefore, the type of crop the household produces is not restricted by the number of family members of working age living in the household. The number of dependents in the household, both very young and very old family members, is not included in this analysis. While a high number of dependents may take away from time others need to work on agricultural production, we do not feel this correlation is strong enough in the Trifinio region to warrant the inclusion of a separate variable in our examination.

II.7 Model Specification

The explanatory variables included in Model 1 are: time in minutes from the household to the main road (*timemainrd*), amount of rainfall in the municipality where the household is located (*rainfallmm*), altitude where the household is located (*altitude*), total manzanas farmed by the household (*totalmzfarmed*), the presence of irrigation on the farm (*irrigation*), the age of the household head (*agehh*), the age of the head of the household squared (*agehh2*), a country indicator for Honduras (*honduras*), the gender of the head of the household (*femalehh*), and lastly, the head of the household's membership in a producer organization (*producerorg*).

We expect that as time to the main road increases, the probability of fruit and vegetable production will decrease. We hypothesize that isolation, as proxied by time to the main road, leads to a lower likelihood of fruit and vegetable production. Isolated households are farther away from both input and output markets, and they grow more food for their own consumption as compared to less isolated households. Fruit and vegetable production is more expensive than staple crops production, and we predict that the farther households are from a main road, the less likely they are to devote any portion of their land to fruit and vegetable production. Amount of rainfall in the municipality is predicted to have a positive impact on the probability of fruit and vegetable production, while altitude is predicted to have a negative impact on the probability of vegetable production. Total manzanas farmed by the household is expected to have a positive impact on the likelihood of fruit and vegetable production; the more manzanas a household has to farm, the more likely they will be to devote some of that land to the production of perishables. Fruit and vegetable production is risky, so households with small landholdings may be less willing to switch some of their resources to the production of fruits and vegetables. A household that irrigates some of its farmland is predicted to have a higher likelihood of fruit and vegetable production. The age of the head of the household is hypothesized to be negatively correlated with fruit and vegetable production; that is, as the head of the household gets older, the household is less likely to produce fruits and vegetables. Based on the summary statistics and our knowledge of the Trifinio region, we predict that being located in Honduras increases the probability of fruit and vegetable production. We expect that having a female head of the household reduces the likelihood of fruit and vegetable production, as females may be less knowledgeable of the practices necessary for fruit and vegetable production or be less physically capable than males of the labor required by fruit and vegetable production. Lastly, we predict membership in a producer organization will be positively related to fruit and vegetable production.

Model 1 treats all agricultural households the same despite important differences in production motives. The motive for producing fruits and vegetables may be related to consumption preferences (which would imply a non-separable household model) and a limited ability to purchase fruits and vegetables, or may be purely commercial- the household produces fruits and vegetables to sell them in the market for income. Much of the literature focuses on the decision to participate in the market, as opposed to the more general decision to produce fruits and vegetables. Goetz (1992) focuses on the marketing portion of this decision, ignoring the consumption side. However, Key, Sadoulet and de Janvry (2000) point out that the agricultural household has three choices in dealing with markets- to sell, to buy from them, or to not participate at all. Additionally, we know from this survey data that of those producing fruits and vegetables, there are a significant number that are not selling any fruits or vegetables. It may very well be that specific factors are positively related to selling fruits and vegetables and negatively related to producing fruits and vegetables for consumption. Models 2 and 3 are designed to see whether factors affect these two choices differently. Therefore, households producing fruits and vegetables are divided into two distinct groups- those that produce fruits and vegetables solely for household consumption and those that produce fruits and vegetables to sell the surplus in the market. One variable that will certainly impact these two groups differently is *timemainrd*; we expect time to the main road to be positively related to non-participation in the fruit and vegetable market and negatively related to market participation. Using the same form of model as before, we estimate two additional models: Model 2, a probit model of fruit and vegetable autarky (households that do not sell any fruits and vegetables, but produce them for their own consumption) and Model 3, a probit model of fruit and vegetable production for market participation.

$$Prob(producefvegonly = 1|Z_a) = F(\beta_a' Z_a) + e\ ,\ \ e \sim N(0,1) \qquad \text{(Model 2)}$$

$$Prob(prodandsoldfveg = 1|Z_s) = F(\beta_s' Z_s) + e\ ,\ \ e \sim N(0,1) \qquad \text{(Model 3)}$$

where $producefvegonly$ takes on a value of 1 if the household produced fruits and vegetables in the 12 months before the survey but did not sell any fruits and vegetables in that same period; Z_a is a vector of explanatory variables; β_a is a vector of parameters; and e is a random error term with a standard normal distribution. The variable $prodandsoldfveg$ takes a value of 1 if the household produced and sold fruits and/or vegetables; Z_s is a vector of explanatory variables (the same vector of explanatory variables as Z_a), β_s is a vector of parameters and e is a random error term with a standard normal distribution. The vector of explanatory variables in Model 3 will be the same vector of explanatory variables in Model 2, in order to examine how these variables impact production for consumption and production for sales differently.

The expected impacts of the explanatory variables for Model 2 are the same as in Model 1 with a few critical exceptions. We expect time to the main road to have a positive impact on the probability of fruit and vegetable autarky. Households farther from the main road will be more likely to produce fruits and vegetables for their own consumption, in part due to their isolation from markets. Rainfall is still expected to positively affect the dependent variable, and altitude is still expected to negatively affect the dependent variable. Similarly, an increase in total manzanas farmed is expected to have a positive impact on the likelihood of fruit and vegetable production. The presence of irrigation is predicted to increase the probability of fruit and vegetable production, as before. We predict that older heads of the households are less likely produce fruits and vegetables for consumption only, as they are physically more able to make trips into populated areas to purchase fruits and vegetables, but much older heads of the household are more likely to be autarkic in their fruit and vegetable production. Therefore the variable age of the head of the household is expected to have a negative impact at first, and then a positive impact on the likelihood of fruit and vegetable production for consumption only. A location in Honduras is expected to be positively related to production for consumption. A female head of the household is an interesting variable to analyze; we believe females to be less likely than males to produce fruits and vegetables for sale, but they may be more likely to produce fruits and vegetables for consumption, perhaps in the form of a small garden. Therefore we hypothesize that *femalehh* will be positively associated with the probability of fruit and vegetable production for consumption only. Finally, membership in a producer organization is anticipated to be negatively correlated with fruit and vegetable autarky.

Model 3 tests the impact of the explanatory variables on the probability of producing fruits and vegetables for sale at market. Time to the main road is expected to have a negative impact on the likelihood of fruit and vegetable production, as predicted in Model 1. The farther a household is from a main road, the less likely it is to produce fruits and vegetables to be sold in the market. Transportation costs are higher for households located farther from a main road. The age of the head of the household is expected to have a different impact on the dependent variable in Model 3 than in Model 2; for households producing and selling fruits and vegetables, we expect age to have a positive impact on the likelihood of production for market, but only up until a certain point. As age of the head of the household increases, the household is more likely to participate in the market, but at a certain age, the variable begins to have a negative effect. A location in Honduras and membership in a producer organization are still expected to be positively related to the dependent variable; however, we predict a female head of the household reduces the probability of producing fruits and vegetables for sale at the market.

We have now identified three categories of agricultural households in Trifinio: (i) not producing fruits and vegetables; (ii) producing fruits and vegetables for consumption purposes only; and (iii) producing fruits and vegetables to be sold at market. We assume that each observation in the sample falls into one and only one category and that the regressors are case-specific- each independent variable has a single value for each case (Cameron and Trivedi 2010, p.498) A multinomial logit model is estimated to predict the probabilities of the three different outcomes described previously, given the independent variables from the initial probit models. The multinomial logit model for this analysis can be given as:

$$p_{ij} = \frac{\exp(x_i'\beta_j)}{\sum_{j=1}^{m} \exp(x_i'\beta_j)} \ , \ j = 1, \dots, m \qquad \text{(Model 4)}$$

where x_i are the case specific regressors, $0 < p_{ij} < 1$, $\sum_{j=1}^{m} p_{ij} = 1$, and β_j is set to zero for one of the categories, the base category. The base category in this analysis is households not producing fruits and vegetables, as we are most interested in the impact of the independent variables on the decision to produce fruits and vegetables. This type of model also estimates the marginal effect of the independent variables on the probability a household selects a certain outcome.

Several hypotheses can be examined using this model specification. As time from the household to the main road increases, the likelihood of producing fruits and vegetables for consumption increases relative to the base outcome (no fruit and vegetable production). Isolated households can diversify their consumption by producing fruits and vegetables and are not concerned with transporting the product to a market. As time from the household to the main road increases, the likelihood of producing fruits and vegetables for sale decreases. The more isolated a household becomes, the more expensive it will be to transport fruits and vegetables to market, therefore the more risky the production of fruits and vegetables becomes. Higher rainfall, larger amount of land farmed, and the presence of irrigation are all anticipated to have a positive marginal effect on the production of fruits and vegetables for both consumption and for sale. Conversely, a higher altitude is expected to have a negative marginal effect on fruit and vegetable production regardless of the end purpose of the product. Age of the head of the household is predicted to have the same impact for the two different categories as it did in the respective probit models. Being located in Honduras is expected to have a positive marginal effect on the likelihood of fruit and vegetable production for either purpose, while a female head of the household would be expected to decrease the probability of fruit and vegetable production for sale at market. Participation in a producer organization would improve farmers' knowledge of practices and access to inputs, and therefore is predicted to have a positive marginal effect on fruit and vegetable market participation.

The models outlined in this section are employed to explain the factors affecting production decisions made by rural Trifinio households. Specifically, we are interested in the impact time to the main road (isolation) has on a household's decision to participate in fruit and vegetable production and sell in the fruit and vegetable market.

II.8 Empirical Results

II.8.1 Probit Model Results

Probit model results (Tables 2.3 & 2.4) indicate that several variables expected to be explanatory of fruit and vegetable production are not statistically significant, and that splitting the dependent variable into the two types of fruit and vegetable producers produces coefficients more closely aligned with the relationships we expected.

Table 2.3: Regression Coefficients for Probit Models[1]

	Model 1		Model 2		Model 3	
	fveg		producefvegonly		prodandsoldfveg	
	Coefficient	Std. Dev.	Coefficient	Std. Dev.	Coefficient	Std. Dev.
timemainrd	0.0013	0.0021	0.0045**	0.0023	-0.0052	0.0041
rainfallmm	0.007	0.0005	0.0008	0.0053	0.0003	0.0006
altitude	-0.0002	0.0004	-0.0008	0.0005	0.0005	0.0005
agehh	-0.0135	0.0451	-0.1035**	0.0525	0.1980*	0.1029
agehh2	0.0001	0.0004	0.0010**	0.0005	-0.0023*	0.0012
totalmzfarmed	0.0214	0.0383	0.0892**	0.0399	-0.1705	0.1197
irrigate	0.4543	0.3720	-0.7617	0.6957	1.0019**	0.4583
honduras	0.9406***	0.3009	0.8422**	0.3911	0.4571	0.3915
femalehh	0.0164	0.3290	0.2836	0.3760	-0.4476	0.4615
producerorg	0.2678	0.2673	0.1209	0.3382	0.2943	0.3519
constant	-2.1600	1.3681	-0.2461	1.5892	-6.2850***	2.3799
Number of Observations: 165						
***p<0.01, **p<0.05, *p<0.1						

[1] Table 2.3 displays the coefficients and standard deviations of 3 distinct probit models. The dependent variable for each of the probit models is listed in the third row of the table. Each probit model predicts the probability of the dependent variable by regressing the vector of independent variables on the respective dependent variable. Complete tables for each of the 3 probit models can be found in Appendix A.

Table 2.4: Marginal Effects[2]									
	Model 1			Model 2			Model 3		
	fveg			producefvegonly			prodandsoldfveg		
	dy/dx	Std.Error	P>|z|	dy/dx	Std.Error	P>|z|	dy/dx	Std.Error	P>|z|
timemainrd	0.0004	0.0007	0.530	0.0009	0.0005	0.062	-0.0004	0.0004	0.263
rainfallmm	0.0002	0.0001	0.121	0.0002	0.0001	0.111	0.0000	0.0001	0.628
altitude	-0.0001	0.0001	0.644	-0.0001	0.0001	0.112	0.0000	0.0000	0.344
agehh	-0.0041	0.0137	0.764	-0.0198	0.0100	0.048	0.0162	0.0072	0.025
agehh2	0.0000	0.0001	0.743	0.0002	0.0001	0.037	-0.0002	0.0001	0.015
totalmzfarmed	0.0065	0.0117	0.576	0.0171	0.0077	0.027	-0.0140	0.0098	0.154
irrigate*	0.1545	0.1371	0.260	-0.0997	0.0548	0.069	0.1593	0.1120	0.155
honduras*	0.2687	0.0770	0.000	0.1527	0.0671	0.023	0.0360	0.0350	0.303
femalehh*	0.0050	0.1010	0.960	0.0611	0.0898	0.496	-0.0280	0.0243	0.249
producerorg*	0.0805	0.0792	0.309	0.0230	0.0640	0.719	0.0236	0.0293	0.422
Number of Observations = 165									
(*) dy/dx is for a discrete change in the independent variable from 0 to 1									

As expected, Model 1 does not do a good job of explaining fruit and vegetable production. The only statistically significant variable is *honduras*, and many of the other variables have signs that are inconsistent with our expectations and previous literature. For example, according to the results from Model 1, as time to the main road increases, the probability of fruit and vegetable production is expected to increase. This is at odds with our prediction, and with previous research. Based on these results and our knowledge about how agricultural households make decisions, we attempt to more accurately examine the determinants of fruit and vegetable production in Models 2 and 3. Examining two dependent variables, *producefvegonly* and *prodandsoldfveg*, allows us to separate the production and consumption/sales decision. We can compare the impacts of the independent variables on the probability that an agricultural produces fruits and vegetables for consumption with the impacts

[2] Table 2.4 displays the marginal effects of the independent variables on the 3 dependent variables from the probit models detailed in Table 3. Complete tables for the marginal effects for the 3 probit models can be found in Appendix A.

of the independent variables on the probability that a household produces fruits and vegetables for sale at the market. It should be noted that the dependent variables for Models 2 and 3 have a limited number of observations that are equal to "1"- 28 observations in Model 2 and 17 observations in Model 3. Due to the small number of observations, we take caution in interpreting our results. However, we believe the proportion of fruit and vegetable producers and sellers to be representative of fruit and vegetable production in Honduras and therefore draw some valid conclusions from our results.

As expected, Model 2 results show that time to the main road is positively related (and statistically significant) to fruit and vegetable production. As time to the main road (relative isolation) increases, the probability of fruit and vegetable production for consumption increases. Rainfall and altitude are not statistically significant, but rainfall is positively related to the likelihood of fruit and vegetable production, while altitude is negatively related. Age of the head of the household is significant in this regression and has the expected effect. A household with an older head of the household is less likely to produce fruits and vegetables for consumption only, but at a certain age the relationship reverses and the household is more likely to produce fruits and vegetables for consumption. We expect that in Model 3 this relationship will be the opposite, which it is. The variable *totalmzfarmed* is positively related to fruit and vegetable production and significant at the 5% level. The coefficient for the variable *irrigate* is negatively related to fruit and vegetable production, implying that farm households that irrigate are less likely to produce fruits and vegetables for consumption. It may be the case that those households that have irrigation are going to be producing fruits and vegetables for the market, as irrigation improves the productivity of horticultural farming.

A one minute increase in time to the main road increases the probability of fruit and vegetable production for consumption by .09%. A one millimeter increase in rainfall increases the probability of fruit and vegetable production by .02% while a one meter increase in altitude reduces the probability by .01%. A one year increase in the age of the head of the household reduces the likelihood of production for consumption by almost 2% on average, but this variable has a parabolic relationship, meaning that at some point the probability of fruit and vegetable production for consumption increases with age. From the coefficients in Table 2.3, we know that the age at which the relationship changes from negative to positive is about 52 years. That is, up until at 52, an additional year of age reduces the likelihood of fruit and vegetable production for consumption; while after age 52, an additional year of age increases the same likelihood. An increase in the total manzanas of land farmed increases the probability of fruit and vegetable autarky by 1.7% and movement from no irrigation to irrigation on the farm reduces the probability by almost 10%. Lastly, being located in Honduras increases the likelihood of fruit and vegetable production for consumption by 15% , a female head of the household increases this likelihood by about 6% and membership in a producer organization increases this likelihood by 2.3% on average. While some of the coefficients of these variables were not statistically significant in the probit analysis, we can still gain knowledge about fruit and vegetable production through these variables' economic significance.

Model 3 tests the impact of the independent variables on the probability that a household produces fruits and vegetables to be sold in the market. The coefficient of time to the main road is not statistically significant (p-value of 0.208); but the sign is as expected. An increase in time to the main road has a negative impact on the likelihood of producing fruits and vegetable to be sold at market. On average, a one minute increase in time to the main road reduces the likelihood of fruit and vegetable market participation by .04%. This finding supports the theory that isolation is negatively related and possibly constraining to participation in the fruit and vegetable market. The age of the head of the household is again statistically significant and exhibits a parabolic relationship to the dependent variable. As expected, the signs on the coefficients for *agehh* and *agehh2* are the opposite of what they are in Model 2. Households with very young and very old heads of the household are less likely to produce fruits and vegetables for sale in the market. This follows what we would expect, as a very young head of the household may be too inexperienced to effectively participate in the market, and a very old head of the household may not be healthy enough to manage market participation for the household. At around age 43, the impact of an additional year of age of the head of the household on the production of fruits and vegetables for sale at the market changes from positive to negative. An additional year of age for the household head increases the probability of fruit and vegetable production by 1.6% until about age 43.

Interestingly, the amount of land farmed is negatively associated with fruit and vegetable sales; the marginal effect of a one manzana increase in the amount of land farmed results in a 1.4% reduction in the likelihood of fruit and vegetable production for the market. It may be that larger farms are emphasizing staple crop production for income generation or livestock production as opposed to horticultural crop production. A simple probit regression that regresses *totalmzfarmed* on the probability that an agricultural household raises livestock tells us that a 1 manzana increase in the amount of land farmed increases the likelihood of livestock production by 5.5%. Irrigation is again positively (and significantly at the 5% level) associated with fruit and vegetable production, and a farm that goes from no irrigation to an irrigation system has a 15.93% higher chance of producing fruits and vegetables for sale at the market. As in Model 2, being located in Honduras is positively related to fruit and vegetable production (a 3.6% increase in probability given a location in Honduras). It is pertinent to point out that the variable *femalehh* is negatively related to the probability of fruit and vegetable production for sale. A female headed household has a 2.8% lower probability of fruit and vegetable production for sale as compared to a male headed household. This could be due to a variety of factors including the general lack of acceptance of women as sellers or the other responsibilities of female heads of the household (children, meals, etc.). Lastly, membership in a producer organization is associated with a higher likelihood of fruit and vegetable production for sale (as it did for fruit and vegetable production for consumption in Model 2) by 2.4% on average.

II.8.2 Multinomial Logit Model Results

We have identified three distinct types of agricultural households within our sample of Trifinio households: (i) non-producers of fruits and vegetables; (ii) fruit and vegetable producers for home consumption; and (iii) producers for sales. The separation of the households into these three groups lends itself to analysis through the more general multinomial logit model because we have three unique cases (also referred to as outcomes). Any observation is distinctly one of these types of household and can be classified as such. In multinomial logit analysis, a base outcome must be selected from the total number of outcomes possible. The base outcome in this model is households producing no fruits and vegetables, as we are most interested in identifying the factors that influence participation in fruit and vegetable production. Outcome 2 is the production of fruits and vegetables for consumption and outcome 3 is the production of fruits and vegetables for sale at market. The coefficients for the multinomial logit model are generally interpreted by the sign. A positive coefficient on the independent variable indicates that as the independent variable increases, alternative *j* is more likely to be chosen than the base outcome. Conversely, a negative coefficient on the independent variable indicates that as the independent variable increases, alternative *j* is less likely to be chosen than the base outcome. We also present the marginal effects of changes in the independent variable on the likelihood that outcomes 1 or outcome 2 is chosen. We are interested in the probability that a household falls into one of these two outcome categories: production of fruits and vegetables for consumption and production of fruits and vegetables for sale at market. Model results are reported below in Table 2.5.

Table 2.5: Multinomial Logit Model Results[3]				
	Coefficient	Std. Error	Average Marginal Effects (dy/dx)	Std. Error
Outcome 2 = produce fruits and vegetables for consumption				
timemainrd	0.0069*	0.0040	0.0009**	0.0004
rainfallmm	0.0016	0.0010	0.0002	0.0001
altitude	-0.0012	0.0009	-0.0001	0.0001
agehh	-0.1592*	0.0921	-0.0215**	0.0096
agehh2	0.0016*	0.0009	0.0002**	0.0001
totalmzfarmed	0.1354**	0.0691	0.0178**	0.0073
irrigate	-0.9710	1.2843	-0.1222	0.1400
honduras	1.6576**	.7734	0.1719**	0.0824
femalehh	0.5230	0.6645	0.0661	0.0719
producerorg	0.2453	0.6534	0.0196	0.0716
constant	-1.2580	2.9260	-	-
Outcome 3 = produce fruits and vegetables for sale				
timemainrd	-0.0010	0.0082	-0.0008	0.0006
rainfallmm	0.0007	0.0013	0.0000	0.0001
altitude	0.0010	0.0009	0.0001	0.0001
agehh	0.4134*	0.2202	0.0308**	0.0153
agehh2	-0.0046*	0.0025	-0.0003**	0.0002
totalmzfarmed	-0.3016	0.2440	-0.0227	0.0171
irrigate	1.5696*	0.8317	0.1207**	0.0562
honduras	1.1309	0.7757	0.0642	0.0531
femalehh	-0.8775	0.9108	-0.0673	0.0636
producerorg	0.7721	0.6781	0.0524	0.0477
constant	-13.0466***	5.2115	-	-
***p<0.01, **p<0.05, *p<0.1				

[3] Table 2.5 displays the coefficients and marginal effects for the multinomial logit model. "Households not producing fruits and vegetables" is the base outcome (Outcome 1).

Time to the main road is a significant regressor for only one of the two outcomes, but for both outcomes follows what we found in the probit model analysis. As time to the main road increases, the production of fruits and vegetables for consumption is more likely to be chosen over no production of fruits and vegetables; conversely, as time to the main road increases, the production of fruits and vegetables for sale at the market is less likely to be chosen over no production of fruits and vegetables.

Table 2.5 displays the marginal effects for the multinomial logit model; that is, the marginal impact of a change in the independent variable on the likelihood that outcome 2 or outcome 3 is chosen. For outcome 2, the marginal effects show the marginal impact each of the independent variables has on the likelihood that a household selects the outcome "produce fruits and vegetables for consumption". A one minute increase in time to the main road results in a .09% increases the likelihood of producing fruits and vegetables for consumption only. The age of the head of the household has the same relationship it did in the probit-based Model 2; as age of the head of the household increases, the likelihood of producing fruits and vegetables for consumption only decreases (up until a certain age- for this outcome, around 50 years old- when an additional year increases the household's probability of producing fruits and vegetables for consumption). A one manzana increase in the total land farmed increases the likelihood of producing fruits and vegetables for consumption by 1.8%. Large farms that are far from output markets may elect to produce a small amount of fruits and vegetables for consumption because they cannot buy fruits and vegetables very often and they have some land to "spare". The presence of irrigation on the farm reduces the probability of fruit and vegetable autarky by 12.2%, a location in Honduras increases that same probability by 17.19%. A female head of the household increases the likelihood a household selects outcome 2 by 6.61% and membership in a producer organization increases the same likelihood by 1.96%.

Marginal effects for outcome 3 are displayed in Table 2.5 above. As expected, a one minute increase in distance to market decreases the probability that a household produces fruits and vegetables for sale at the market by .08%. Increases in rainfall and altitude are both positively associated with fruit and vegetable production for sale but not at a statistically significant level. The age of the head of the household is statistically significant in the multinomial logit model for outcome 3. An additional year of age for the head of the household increases the likelihood of producing fruits and vegetables for sale by 3.08%. The amount of land farmed is negatively related to fruit and vegetable production for sale- a 1 manzana increase in the amount of land farmed reduces the likelihood a household selects outcome 3 by 2.3%, though the coefficient is not statistically significant. The independent variable *irrigate* is highly significant for outcome 3- movement from no irrigation system to some irrigation on the farm increases the probability of producing fruits and vegetables for sale by 12.07%. If the household is located in Honduras, the chance of producing fruits and vegetables for sale at the market increases by 6.42% and similarly, membership in a producer organization increase the likelihood of outcome 2 by 5.24%. Gender of the head of the household has the opposite effect for outcome 2 than it had for outcome 1. Household with a female head are 6.73% less likely to produce fruits and vegetables for sale.

The results of the multinomial probit model align closely with the results from probit models 2 and 3, offering further evidence that households producing fruits and vegetables should be treated separately depending on their production motives.

II.9 Conclusions

The results lead us to several important conclusions about the determinants of fruit and vegetable production in the Trifinio region of Central America. Firstly, isolation from a road network is a significant deterrent to market participation. Time to the main road consistently has a negative impact on the probability of fruit and vegetable market participation. Time to the main road is positively related to production of fruits and vegetables for own consumption, further supporting the hypothesis that isolation is an important factor in the farm household's decision making process. In Trifinio, access to markets is achieved via the road network, and households located off the beaten path are less likely to participate in fruit and vegetable markets. These findings parallel Von Thünen's theory of the isolated state: the most expensive crops to transport will be produced closest to the central market. The introduction of a road or a waterway in the Von Thünen model will alter the location of activities; the expensive-to-transport crops may be produced near a road or waterway even if said feature is far from the central market. Our findings tell us that as the distance between an agricultural household and the main road increases, the probability of fruit and vegetable production for sale decreases. From this finding, we infer that households very close to the main road and/or close to the markets are likely the households producing the majority of fruits and vegetables for sale.

The decision over which inputs to use and in what quantities to use them is integral to the overall production decision. Inputs such as irrigation, pesticides, and fertilizer are vital to the production process and this analysis finds irrigation to be significantly and positively correlated with fruit and vegetable market participation. IPM practices often alter the inputs utilized by the farm, and IPM and irrigation may therefore have a similar impact on fruit and vegetable production. We predict that access to IPM information is positively related to the probability of fruit and vegetable production. Uncertain rainfall combined with abundant surface water makes irrigation technology critical to commercial production of perishable crops in Trifinio. Households with access to such technology are much more likely to participate in markets. Irrigation is also tied to a household's isolation: the more isolated a household is, the less likely that household is to have an irrigation system in place on their land, and thus the less likely that household is to participate in fruit and vegetable output markets. We consistently found that older heads of the household are more likely to participate in fruit and vegetable markets, but that very old and very young heads of the household of less likely to do so. Knowledge of fruit and vegetable production and markets increases with age, but very old heads of the households may be less physically capable of managing fruit and vegetable market participation.

Most farm holdings in the Trifinio region are small, but even a small increase in the amount of land farmed has a positive impact on the likelihood of fruit and vegetable production for consumption. The probability of fruit and vegetable production for sale at market is negatively impacted by an increase in the amount of land farmed. Perhaps farms initially producing some fruits and vegetables are encouraged to switch to staple crop production if their farm holdings increase because the economies of scale from the production of staple crops are greater than those from fruit and vegetable production. Geographic factors such as rainfall and altitude are less explanatory of fruit and vegetable production than other types of factors. The rough terrain and high elevations of the Trifinio region are not significant determinants of fruit and vegetable production for consumption or sale, indicating either that farmers in this region use production practices that overcome seemingly challenging geographic features or that geographic features do not impact crop choice.

Another interesting aspect of this study is the inclusion of a variable that accounts for the gender of the head of the household. While the number of households run by females is low in this sample of Trifinio households, gender does seem to have an impact on the type of crops produced. Women-run households are generally less likely to participate in fruit and vegetable markets but more likely to produce fruits and vegetables for household consumption. There may be several reasons for this relationship. Societal norms may discourage women from participating in markets; if a woman feels she is not going to be accepted as a seller, she may opt out of the market process and choose to produce only for her own family's needs. Women may have an inclination for the production of perishables on a small-scale (as in a garden), which may explain why a female head of the household makes a household more likely to produce fruits and vegetables for consumption only. Throughout all the analyses in this study, membership in a producer organization is positively associated with the production of fruits and vegetables. Whether the perishable crops are produced for consumption at home or for sale at the market, a household that is a member of a producer organization is more likely to produce them. There is a strong correlation between this type of support and the production of high-value crops. Households receiving support from agricultural organizations- be it educational or financial- are more likely to participate in the production of high-value fruits and vegetables.

We have identified several of the determinants of fruit and vegetable production for agricultural households in the Trifinio region of Central America. We separate fruit and vegetable production into two groups- those producing for household consumption and those producing to participate in the market. Results indicate this separation is valid and important, as many of the independent variables tested influence production differently depending on the production motive. Overall, distance to the main road, and thus distance to market, has a negative impact on the likelihood of fruit and vegetable production for sale at the market.

II.9.1 Limitations of Study and Future Research

While our study yields insight into the household's decision to produce perishable crops, it is limited in the variables we were able to study. It would be pertinent to include environmental variables, such as land quality and better rainfall data, however it is difficult to find good measures of environmental determinants of production. In addition to travel time to the main road, we looked at road quality as a factor. The survey asks respondents whether their access road is paved or not, as well as how often it was passable in the year before. This paved access road variable is highly correlated with our study's *timemainrd* variable. This combined with the way the question was asked led us to exclude the variable from our study. During the initial analysis of the survey data, we constructed an asset index- a score given to each household based on how many of the 36 selected assets they possessed. However this asset index showed that on average these households had only 5 of the 36 assets and most of the assets that were asked about did not relate to agricultural production. For these reasons, an asset index variable was not included in regression analysis.

Distance to the main road is utilized as a proxy for distance to the market in this analysis due to time constraints; however, future research could utilize geographic information systems (GIS) software to obtain the distance to the nearest market for each of the observations in the sample. We expect the results of such an analysis to be similar to the results found here, but there may be some important differences as the values of the "distance" variable would change, perhaps changing the impact of the "distance" variable on the dependent variables selected.

Future research on this topic should look at the impact of distance to market on agricultural household decision making in other developing countries to see if the relationship is similar across several geographic areas. Additionally, future research can analyze the relationship between distance to market and market participation as a two-stage process: the first stage, where the household decides whether or not to produce the crop (say, tomato), and the second stage, where the household determines the quantity to sell at the market. The determinants of the dependent variables may be different for the two different stages of the decision process. This type of analysis will provide further insight into the role distance to market plays in the agricultural household's production decisions.

II.9.2 Contributions and Policy Implications

This study contributes to literature on agricultural households and distance to market. The body of literature on distance to market is far from robust but vital for a complete understanding of agricultural households, and this analysis further supports the generally accepted principal that distance to market impacts agricultural household decision making. Additionally, the results of this analysis follow the theory originally outlined by Von Thünen- the theory that agricultural goods that are expensive to transport are going to be produced close to a central city or main access route. This paper also contributes to the much smaller body of literature that looks at crop choice- how agricultural households decide which crops to produce, and furthermore, which crop markets to participate in. Our analysis shows that for agricultural households in Honduras, perishable crop production is limited by distance to market, input usage, head of the household characteristics, and the amount of land available.

Numerous policy implications arise out of this study, especially for policies pertaining to infrastructure and agricultural extension work. As developing countries look to improve the welfare of their people, they must consider new and improved infrastructure as a way to open up opportunities. Building of new roads and repair of existing roads reduce transportation times and costs. A reduction in transportation costs may allow some households to participate in markets they could not participate in before the reduction, while also decreasing the cost of obtaining critical inputs, such irrigation system supplies. This market participation can lead to higher incomes and an overall welfare improvement.

Those working in agricultural extension should consider the impact access to credit has on a farmer's ability to utilize certain inputs. From this study we know that an irrigation system is an important determinant of fruit and vegetable production. Extension agencies would be well served to further investigate the role input access plays in the rural household's crop choice decision. Additionally, extension agents may look into the role IPM plays in reducing a household's dependence on input markets, and the subsequent improved viability of fruit and vegetable production. The role of gender has become an increasingly important and popular topic in agricultural economics literature, and this study suggests that females are less likely to participate in the perishable crop market than males. Programs that educate women about market participation and educate men on the merits of conducting business with female farmers may help increase the number of women participating in high-value crop markets in developing countries. Lastly, the role of producer organizations is highlighted in this study. Membership in a producer organization is positively related to fruit and vegetable, so extension agencies again would be well served to promote membership and work to make it easier for farmers and producer organizations to connect throughout the agricultural production chain.

CHAPTER III: INTEGRATED PEST MANAGEMENT, DISTANCE TO MARKET, AND CROP CHOICE: A LINEAR PROGRAMMING ANALYSIS

III.1 Introduction

In many areas of Central America, road coverage is uneven and many farmers find themselves isolated from markets. Evidence shows that distance to market affects input use and farming intensity, yet there is little evidence about the effect of distance on integrated pest management (IPM) adoption. IPM is "a long-standing, science-based, decision-making process that identifies and reduces risks from pests and pest management related strategies. It coordinates the use of pest biology, environmental information, and available technology to prevent unacceptable levels of pest damage by the most economical means, while posing the least possible risk to people, property, resources, and the environment" (National Road Map for Integrated Pest Management, 2004). IPM practices can be implemented at all stages of the agriculture production process, from soil preparation to pesticides application to post-harvest. There are four broad steps in the IPM approach: 1.) identification 2.) prevention and exclusion 3.) monitoring and 4.) multiple tactics (Pennsylvania Integrated Pest Management, 2012). Identification of the pests is essential for appropriate control method selection. Prevention and exclusion are the practices that stop pests from becoming a problem in the first place, while monitoring allows problems to be spotted early and often. The use of multiple tactics for pest control permits chemical control to be a last resort. Globally, much work is being done in developing countries to implement IPM, raise living standards, and prevent environmental damage (USAID IPM-CRSP). USAID has IPM projects in Africa, Asia, and Latin America and the Caribbean, and many focus on IPM for the poorest farmers.

Poor farmers in developing countries face many obstacles in their daily lives- food security concerns, limited access to input and output markets, risk, limited access to credit, limited income opportunities, and isolation due to few roads in general and even fewer paved roads. Due in part to these obstacles, poor Honduran households produce staples- mainly maize and beans. Staple production is typically less profitable than horticultural crop production (fruits and vegetables), and if Honduran farmers can switch some or all of their production to horticultural crops they may very well see higher farm profits and higher income. Broadly speaking, IPM has been shown to be particularly good for vegetable crops as it can improve yields, increase profits, and reduce production costs.

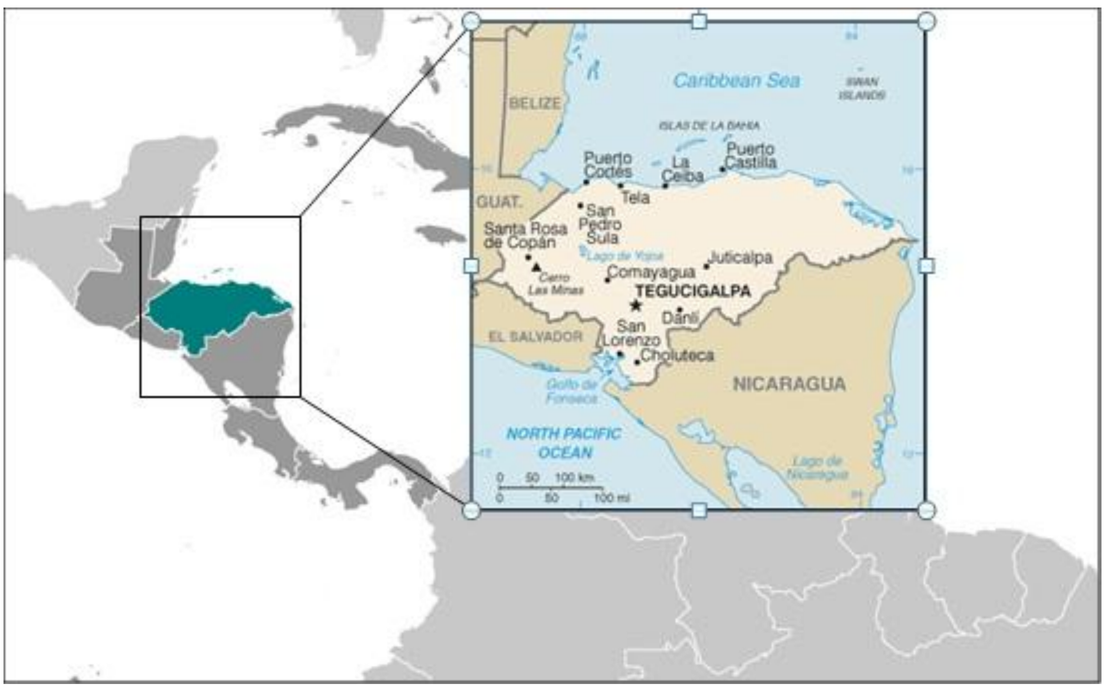
The objective of this study is to identify and analyze the impact distance to market has on crop mix and technology selected by small-scale Honduran farmers. Additionally, we analyze scenarios in which the distance to input market, labor usage, and food security requirements are varied. This study analyzes how distance to market impacts the profitability and viability of IPM techniques, how distance to market impacts decisions to utilize IPM or conventional practices, and how the use of IPM production techniques impacts the crop mix selected by Honduran agricultural households.

The study is laid out as follows. First, we provide a broad description of conditions in rural Honduras and conditions related to IPM adoption and use. This information gives context for our subsequent conceptual framework and analysis. We utilize data from a household survey and production budgets from agricultural research and extension agencies to construct a linear programming model of a representative Honduran farm. We analyze the impact of distance to market on the crop and technology choice made by smallholder. Subsequently, we model additional scenarios, including varying the distance to the input market, relaxing the food security constraints, allowing the household to hire in labor, and restricting the household to one technology type per crop. Results indicate that there is a critical distance beyond which Honduran farms cease production of vegetables and only produce staple crops.

III.2 Background

Nestled between Guatemala to the west, El Salvador to the southwest, and Nicaragua to the southeast is Honduras, a country bordering both the Pacific Ocean and the Caribbean Sea.

Figure 3.1: Honduras



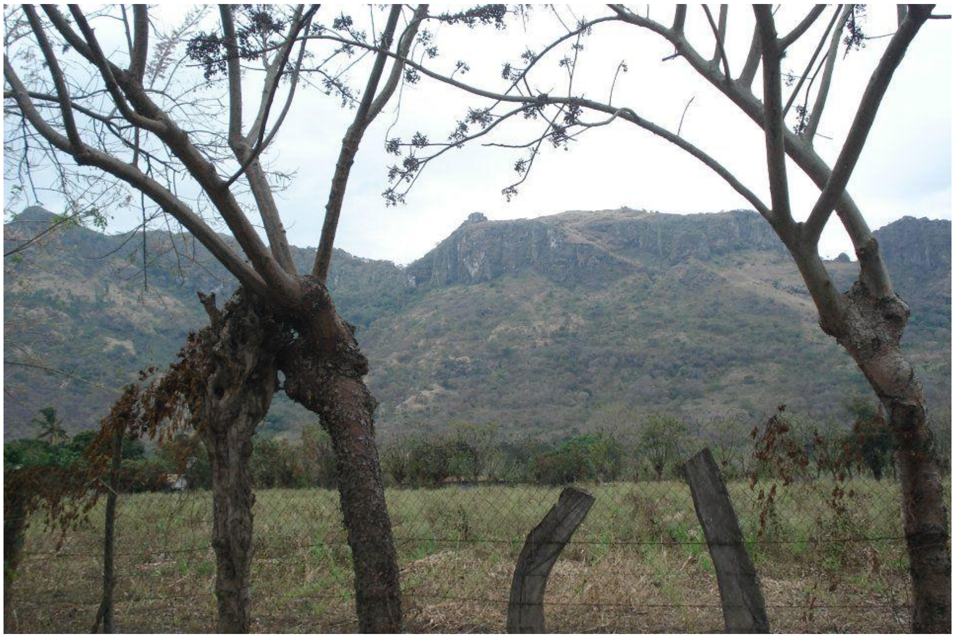
Source: CIA World Factbook

The country has a mountainous terrain and a generally temperate climate (with the exception of the sub-tropical low-lying areas). The capital Tegucigalpa and several other cities and tourist areas (San Pedro Sula, Santa Rosa de Copán, and La Ceiba) are major markets. Honduras is the second poorest country is Central America, characterized by a highly unequal distribution of income. In 2007, the poorest 10% held 0.6% while the highest 10% held 43.8% of the income made in the country (CIA February 2012). Out of 8.3 million people, 65% live below the poverty line (CIA February 2012). There is an enormous income gap between the wealthy and the poor.

Economic activity in rural areas is dominated by agricultural production, and agricultural production accounts for 22% of gross domestic product (CIA February 2012). Some of the most important agricultural products are coffee, bananas, citrus, corn, and African palm. Coffee and bananas are the largest export crops (CIA February 2012). Agriculture is the second largest sector for employment in Honduras, employing 40% of the labor force. Economic activity is also closely tied to the United States- exports to the United States make up 30% of gross domestic product (CIA February 2012). The export market is vital for many Honduran farmers.

Transportation in Honduras is difficult due to mountainous terrain and poor roads. There is a predominance of dirt roads in the country- 78% of roadways in the country are unpaved (CIA February 2012). Travel by road takes longer than it would if more of the roads were paved and this isolates many rural households from the more populated areas. Below is a picture taken from a rural road outside Tegucigalpa, Honduras. It shows the mountainous terrain that makes road travel difficult throughout the country.

Figure 3.2: View of mountainous terrain from a rural road outside Tegucigalpa, Honduras



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Rural roads are more likely to be unpaved and are often impassable during bad weather; 13% of unpaved roads are impassable during the rainy season (CIA February 2012). Even when dirt roads are available to rural Hondurans, they are often uneven and rutted, as seen in the photograph below.

Figure 3.3: Rural road in Guinope, Honduras

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Uneven roads increase travel times, worsen wear and tear on vehicles, and may damage crops during transit, specifically fruits and vegetables.

III.2.1 Agricultural Households in Honduras

Agricultural households vary across Honduras, but they share common characteristics that can be useful in understanding their decision making. Much of the information detailed in this section is from a 2007 International Food Policy and Research Institute survey of El Salvadorian, Guatemalan, and Honduran households (International Food Policy Research Institute and Plan Trifinio, 2007). We believe the information to be representative of many agricultural households in Honduras, because the majority of these Trifinio households are poor and their landholdings are very small- traits shared by the majority of agricultural households in Honduras.

Honduran households in this sample typically own small amounts of land and farm even less. The average amount of land owned is about 7.15 manzanas (1 manzana = 0.7 hectares = 1.73 acres) and the average amount farmed is about 4.29 manzanas. Many of these small farms are semi-commercial, meaning they produce crops for both household consumption and sale at market. Households in the area produce a variety of crops, including maize, beans, tomatoes, onion, potato, peppers, lettuce and carrots. There are 6 people on average living in the agricultural household. On average, 17% are female headed households, and the head of the household only has beyond a primary school education 6% of the time. The average age of the head of the household is 48. Additionally some households own a vehicle for use on the farm and some do not. About 13% of the Honduran agricultural households in this sample have irrigation on their farms, and only 12% have an access road that is paved. The average travel time to the main road is 49 minutes. However, travel time to the main road can be as high as 4 hours for the most isolated rural households. These types of households utilize family labor for work on the farm, as well as hire in labor at a daily wage ranging from $5.25 to $8.25 a day, depending on the labor activity (Fintrac, 2011). The preceding data is representative of many agricultural households in Honduras, and helps set the context for our analysis of distance to market and agricultural household production decisions.

III.2.2 Integrated Pest Management in Honduras

In Honduras, there is no public agricultural extension service. As a result, agricultural assistance and extension work must be carried out by private organizations, educational institutions, and non-governmental organizations. Several organizations currently disseminate IPM information. The stated purpose of the USAID-funded program IPM CRSP LAC (Integrated Pest Management – Collaborative Research Support Program Latin America and the

Caribbean) is “to develop and implement a replicable approach to IPM that will reduce the following: agricultural losses due to pests, damage to natural ecosystems including loss of biodiversity, and pollution and contamination of food and water supplies” (IPM CRSP 2011). The IPM CRSP also has goals of increasing farmer income, reducing pesticide use, and improving IPM research and education program capabilities. The LAC regional program specifically focuses on perennial and vegetable crops in Honduras, Guatemala and Ecuador. Perennial crops “help reduce poverty and food insecurity, and provide engines of growth for lagging regions” (IPM CRSP 2011).

The Honduran Agricultural Research Foundation (FHIA) headquartered in La Lima, Honduras is a partner in the IPM CRSP. FHIA’s vegetable program, based in the horticultural region of Comayagua, seeks alternative solutions to pest problems in a way that improves local producers’ market competitiveness. FHIA also hosts events for extension agents, vegetable producers, and small farmers so they may come and learn about different pest technologies and practices. The picture below is from a February 2012 farmer field day, where over 100 participants came to the field station and were educated on different practices. The practice shown below is a type of exclusion strategy that utilizes Agribon mesh to keep pests and weather elements away from tomatoes. This practice (known as mega or macro-tunnels) creates a greenhouse like atmosphere for the crop and while not widely used in Honduras, has provided great benefits for tomato farmers in Guatemala.

Figure 3.4: Covered crop technology at FHIA Field Station in Comayagua, Honduras

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Zamorano University, an agricultural university just southeast of the capital, houses PROMIPAC (Central America Integrated Pest Management Program). PROMIPAC works closely with rural Honduran farmers, providing them with information about IPM practices and collecting data from them regarding production costs and yields. PROMIPAC regularly checks in with the farmers they work with, monitoring their practices and providing information about IPM strategies and practices. They are an important source of information and support for the most rural and poor of Honduran farmers. Lastly, the organization Fintrac administers the USAID-funded program ACCESSO in Honduras. This program "focuses on moving rural Honduran households out of extreme poverty and under-nutrition by improving their income through a combination of on-farm income productivity and diversification activities, combined with off-farm business expansion and employment generation" (Fintrac, 2012). Fintrac strives to open access to new production practices, inputs, and markets to the smallest and poorest farmers in Western Honduras. Fintrac works directly with farmers to teach IPM practices and assists them in obtaining inputs, accessing markets, and increasing revenue and income.

A wide variety of IPM practices are currently being used in Honduras. These practices range from very basic (such as removing weeds during and after the crop cycle) to highly advanced (and expensive- such as the covered production seen in Picture 3). Some other basic practices are: new seed varieties, scouting for pests before spraying and raising seed beds. Raised seed beds are prevalent in Honduras and several extension agents touted this as one of the first practices they recommended to small farmers. Slightly more expensive techniques include the planting of a natural barrier (such as maize) around the crop, the use of biological pesticides (natural enemies that combat unwanted pests), and insect traps. Drip irrigation is also important for production and allows use of soluble fertilizer. Several advanced techniques are known in Honduras but are not yet widely used. These include mechanized irrigation (very high fixed costs as well as requires access to electricity), grafting, and covered production. Covered production (utilizing mesh such as Agribon) can be expensive because the mesh only lasts for one, maybe two, crop cycles and then must be thrown away and repurchased. As mentioned before, this technique is very popular in Guatemala, so extension agents are hopeful it will become more widespread in Honduras.

Farmers learn of IPM practices through several avenues. For one, if they live near a field station they can attend a farmer field school or a farmer field day. Here farmers get one-on-one or small group attention on what technologies will work for their farms. Sometimes farmers are visited at their home by a PROMIPAC, FHIA or Fintrac agent. The agent then begins a relationship with the farmer, educating and monitoring their progress. Farmers may hear of IPM practices by word-of-mouth, from neighbors or area farmers when they travel to market. They also may have a neighbor utilizing IPM that they can visit or have a “model-farm” in the area where they can visit and see the technologies in practice. Lastly, paper products such as pamphlets and calendars are utilized to spread IPM information and can educate literate farmers.

III.3 Previous Literature

III.3.1 Transactions Costs and Market Access

There is significant literature on transactions costs and the impact these costs have on both farmers’ production and marketing decisions. Alene et al. (2008), Stifel, Minten and Dorosh (2003), Omamo (1998a, 1998b), and Key, Sadoulet, and de Janvry (2000) all look at the impact transactions costs have on farmers choices. Alene et al (2008) found that as distance to the maize market increases, maize supply decreases, and when distance to the input market increases, both market participation and maize supply decrease. Omamo (1998a, 1998b) concluded that diversification is a positive and rational decision for farm households depending on their market access, and farmers respond to high-transportation costs in Kenya by routinely producing low-yield crops instead of cash crops. Key, Sadoulet and de Janvry (2000) conducted a study on Mexican producers’ decision to buy in the market, sell, or not participate in the market at all. They found market participation is conditional on fixed and proportional transactions costs, while the decision of how much to supply is conditional only on proportional transactions costs. They also concluded that the main factors that increase corn production by sellers are access to credit, high output prices, and the use of high-yield seed (Key, Sadoulet, de Janvry 2005, p.255).

Winter-Nelson and Temu (2004) found that travel costs in input and output markets have "distinct effects on input usage, implying distinct avenues for interventions to promote more intensive use of agricultural inputs" (p.243). They also concluded that travel costs to the market "diminish the probability of using purchased inputs" based on the negative and significant coefficient on remoteness in their model (Winter-Nelson and Temu, 2004, p.249). This conclusion offers support for this paper's prediction that as isolation increases, input usage declines, constraining the production of input-intensive crops like fruits and vegetables. Looking generally at market access for Malawi farmers, Zeller, Diagne and Mataya (1997) postulated that "must-needed increases in household income… come from gains in agricultural productivity and more profitable crops" (p.ii). They find that "differences in the household's access to financial and commodity markets significantly influence its cropping shares and farm income" (1997, p.ii). Markets play an important role in crop choice for Malawi smallholder farmers. The authors findings support their conclusion that market access and rural infrastructure improvement are essential for technology adoption and the "transformation of subsistence-oriented smallholder agriculture" (1997, p.19).

Looking specifically at the impact of rural road improvements on access to market for very poor households, Jacoby (2000) concluded with data from Nepal that better road access to markets would have many benefits, but specifically benefits for poor households (p.713). The author touts roads as particularly important for "cheap access to both markets for agricultural and for modern inputs" (2000, p.713). In another study of market decisions, Fafchamps and Vargas Hill (2005) analyze the choice between selling at the farmgate and traveling to market to sell product. With information from Uganda, they find that "selling to the market is more likely when the quantity sold is large and the market is close by" (Fafchamps and Vargas Hill, 2005, p.717).

Fafchamps and Vargas Hill conclude that selling at the farmgate is less profitable but may be the only option for farmers who are too poor to transport their crop to the usually distant market, and state that farmers welfare can by improved through institutional improvements, like producer cooperatives (2005, p. 717). Their conclusions support our belief that distance to market is a significant constraint for agricultural households.

The literature shows that as distance to market increases, input usage decreases, market participation decreases, and reliance on staple crops typically increases.

III.3.2 Integrated Pest Management Systems and Adoption

Several studies examine factors influencing adoption of agricultural innovation and technologies. Feder, Just and Zilberman (1982) conducted a survey of literature pertaining to agricultural innovation specifically in developing countries. Conventional wisdom tells us that constraints to innovation adoption include lack of credit, limited access to information, risk aversion, limited farm size, unreliable input supply, and insufficient transportation infrastructure (Feder, Just and Zilberman, 1982). It is generally expected that if these constraints are removed, not only will technology adoption increase, but the crop composition will change (1982). In their survey, they treat profit as dependent on a "discrete selection of mix of technologies including the traditional technology and a set of components of the modern technology package" (1982, p.17). They suggest one approach for looking at the technology choice where the farmer chooses between two technologies, a traditional technology and a modern technology; the researcher in this approach investigates how much land is allocated to each technology and how much inputs are used. This approach is analogous to the method utilized in our study. Byerlee and Hesse de Polanco compared two adoption tactics: stepwise adoption and package adoption. They found that farmers rationally use a stepwise process to adopt different technologies; often farmers are not in a position to adopt complete packages (this may be due to capital scarcity and risk) (Byerlee and Hesse de Polanco, 1986). The authors conclude that while packages are developed to be implemented all at once, this should be a goal over a period of time, as most farmers do not have the resources to adopt in this manner initially (Byerlee and Hesse de Polanco, 1986). In our study we will look at technology adoption as a stepwise procedure, moving from traditional farming (low-technology) to some IPM technology usage (medium-technology) to advanced IPM technology usage (high-technology). Turning to the literature on IPM information dissemination, a 2007 paper by Mauceri, et. al. found that field days, pamphlets and farmer field schools have strong impacts on adoption, although farmer field schools are very expensive (p.765). The authors also came to conclusions regarding the use of IPM methods- input costs were significantly lower on IPM plots, yields were equal, and profits were higher (Mauceri et. al, 2007). They also look at the impact of distance to market on the profitability of IPM and found that distance to market lowers farm-gate prices of outputs, raises prices of inputs, and makes information more costly to obtain (Mauceri et. al, 2007, p.770). This finding is important to our study because we seek to discover what impact distance to market has on both technology choice and crop choice.

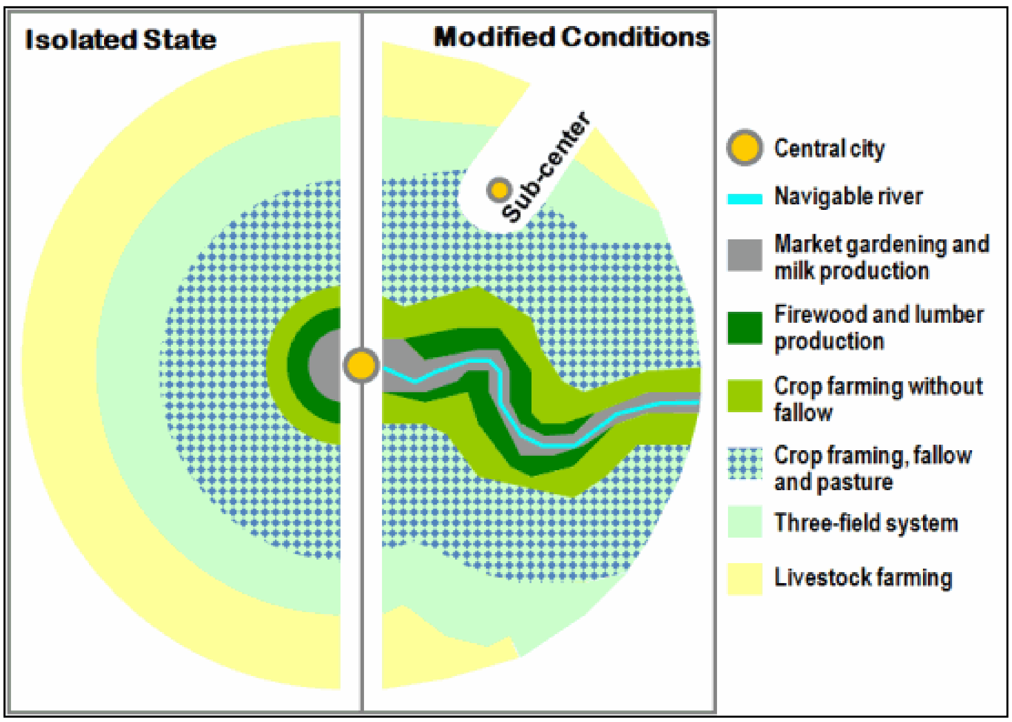
In a study of IPM adoption by Wisconsin farmers, Hammond et. al found that large farms and cash-grain production both made farmers more likely to rotate crops, rotate herbicides, and implement practices that promote environmental safety (Hammond et al., 2006). Large-scale farmers also reported scouting more often than small-scale farmers, and applying pesticides less often (Hammond et al., 2006). These findings indicate that the type of crop produced does have some influence on the usage of IPM practices. An early analysis of IPM adoption from Greene et al. (1985) analyzed risk as a determinant of a farmer's adoption of a pest management strategy. They find that both risk-averse and in some cases, risk-preferring farmers would prefer an IPM approach to a chemical control approach given the net revenues of the two options (Greene, et. al. 1985). This finding supports our prediction that given a choice between IPM and non-IPM production strategies (holding other variables constant) IPM is the more profitable and more likely to be used strategy. Another study in the vein of IPM vs. conventional production was conducted in 1996 by Cowan and Gunby and argues that there are many reasons why conventional production has remained popular despite the proven benefits of IPM production. One reason for this is the knowledge intensive-nature of IPM, and also the fact that IPM practices typically necessitate good farm management skills (Cowan and Gunby, 1996). Another important factor for those considering IPM adoption is technological uncertainty; if farmers believe they cannot accurately predict the results of adoption, they are less inclined to adopt in the first place. Cowan and Gunby suggest support for research and development and extension services can overcome these issues, and go further to say that perhaps this support should be geographically concentrated- because there are economies of scale associated with a higher number of people in one region adopting IPM (1996, p.539).

A few studies directly examine the impact IPM technology adoption has on the shift to production of high-value vegetables, as well as how the adoption of IPM impacts farmers that are already producing vegetables. Fernandez-Cornejo, Beach, and Huang look specifically at IPM adoption by vegetable growers in three U.S. states (1994). Vegetable growers adopting IPM are less risk-averse, spend more managerial time on farm activities, tend to operate larger farms with irrigation, and utilize more family labor than their non-adopting counterparts. The type of crop and location of the farm are important correlates of IPM adoption. Additionally, the production of livestock has a negative effect on IPM adoption, and irrigation and IPM are found to complement each other (Fernandez-Cornejo, Beach and Huang, 1994, p.168). All these factors-farm size, risk, family labor, irrigation, type of crop, location, and livestock are important to consider in our analysis of how IPM impacts crop choice. In a later study on the impact of IPM on agricultural diversification in Bangladesh, Mahmoud and Shively use an optimization model "to study crop and technology choice under price and yield uncertainty" (2002, p.187). Results indicate that access and availability of IPM combined with access to credit improve household welfare and lead to higher rates of vegetable production, while off-farm employment opportunities reduce the likelihood of vegetable production (Mahmoud and Shively, 2002, p.187). Risk-neutral households shift completely from rice to vegetable production and the area used for vegetable production increases by 28%; income and consumption increase by 46 and 40%, respectively when IPM is adopted as compared to the no IPM scenario (Mahmoud and Shively, 2002, p.187). This paper is especially relevant to our study, as we expect similar results when we look at the impact of IPM adoption on the choice between staple crop production and vegetable production.

III.4 Conceptual Framework

The framework for this study is centered on von Thünen's theory of the isolated state. In his work, von Thünen describes a large town on a great fertile plain, isolated from other towns. Because of this isolation, the central town must supply the entire area with manufactured products, and conversely, the surrounding area provides the central town with agricultural goods (von Thünen, 1966). The essential problem becomes "What pattern of cultivation will take shape in these conditions; and how will the farming systems of the different districts be affected by their distance from the Town?" (1966, p.8). He concludes that heavy, bulky, perishable and expensive to transport goods will be produced closest to the central town, and as distance increases, land will be used to produce cheaper-to-transport products. The relative transportation costs of different agricultural commodities determine where the commodities will be produced. This theory can be visualized with concentric rings, with each ring representing land for the production of a particular good. Figure 3.5 below demonstrates Von Thünen's isolated state model.

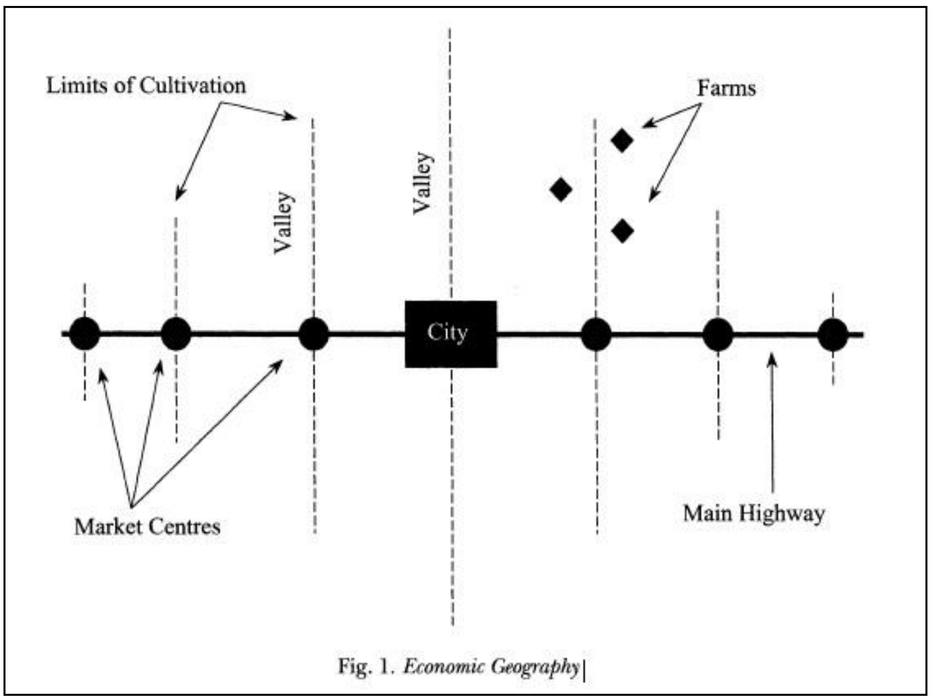
Figure 3.5: Von Thünen's Isolated State
Used with permission of Dr. Jean-Paul Rodrigue, 2012



The "modified conditions" on the right-hand side of Figure 3.5 show how the rings change shape given the introduction of a river, road, or new market center. These features open opportunities for perishable/expensive/bulky goods to be produced far from the central town as long as they are near one of these geographic features. In our study, we anticipate that horticultural crops (fruits and vegetables) will be produced close the main market (they are more expensive to transport), and staple crops, such as maize and beans, will be produced further away from the market. In addition to the type of crop produced, the cost of inputs, price of output, and access to/cost of information are all affected by distance.

Figure 3.6 illustrates Von Thünen's theory another way. Market centers are located along the main road, and cultivation takes place within a certain distance from market centers. Beyond some geographical limit, cultivation will no longer take place.

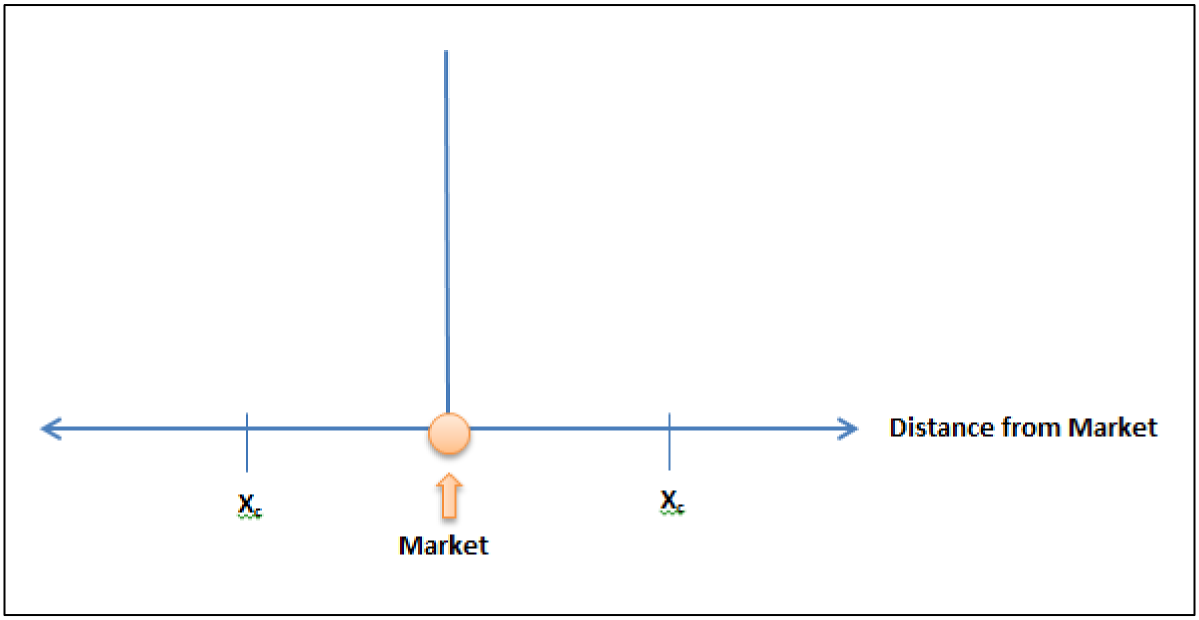
Figure 3.6: Market centers and limits of cultivation



Source: Jacoby, 2000

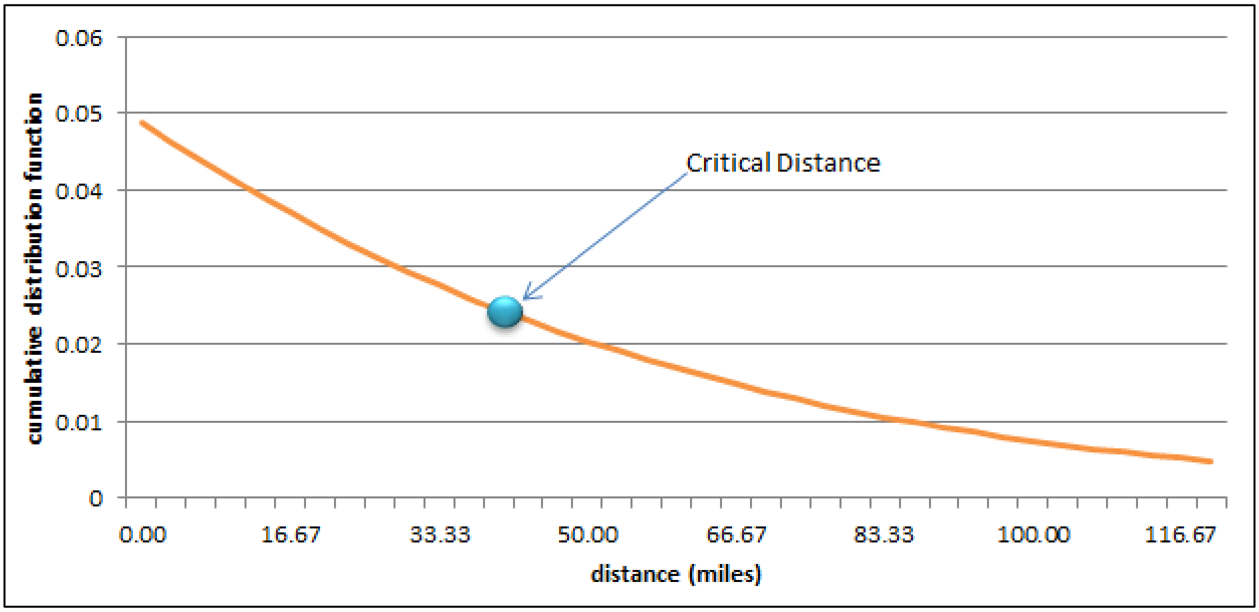
Using Von Thünen's theory as a basis for our research, we expect that fruit and vegetable production will take place closer to the central market and staple crop production will take place further from the central market. Beyond some critical distance X_c, no fruit and vegetable production will take place.

Figure 3.7: Critical Distance



An econometric analysis of the previously mentioned IFPRI Trifinio Survey guides this analysis. We gained information about the impact of several variables on the likelihood of fruit and vegetable production for sale at the market, as well as on the likelihood of fruit and vegetable production for consumption within the household. Of particular interest to this linear programming analysis is the finding that beyond a specific distance the likelihood of fruit and vegetable production becomes low enough to safely assume that no fruit and vegetable production for sale will occur beyond that distance. To calculate this distance, we estimated a probit model where the production of fruits and vegetables for sale at market is the dependent variable (See Table 2.3 in Section II.8.1). The coefficients from this estimation are used to calculate the probability of fruit and vegetable production at the average values of the independent variables with time to the main road being varied from 0 minutes to 180 minutes. The cumulative distribution function was then computed. Time to the main road was converted to distance to the main road based on an approximate travel speed of 40 miles per hour.

Figure 3.8: Probability of fruit and vegetable production over distance to the main road[4]



At the critical point of 43 miles (identified in Figure 3.8), the probability of fruit and vegetable production is 50% lower than when the household is located directly next to the main road. Distance to the main road is different from distance to the market, but we believe this to be a good approximation of the point after which no practical fruit and vegetable production occurs. Therefore, we expect a linear programming analysis of a representative Honduran farm to yield similar results- beyond 43 miles, tomato, onions, and potatoes should not be selected by the model.

A farmer's ability to learn about IPM practices and technologies is also impacted by distance to market; the farther from a central town, the less able he/she is to hear of these new practices. Additionally, as distance to market increases, producers face higher input and transportation costs. As a result, farmers receive a lower effective output price when they sell

[4] Own calculations using results in Table 2.3

their products at market. Differences in transportation costs vary by crop however, as some crops are cheaper to transport than others.

Integrated pest management adoption is affected by distance to market because IPM practices reduce the amount of inputs necessary for production. IPM impacts the crop mix selected by the farm because it increases the relative productivity of input-intense fruit and vegetable production (as compared to conventionally produced fruit and vegetables and the production of staple crops like maize and beans). Consequently, IPM practices may help distant farmers participate in fruit and vegetable production by making them less dependent on input markets. A reduction in dependence on the market makes distance to market less of a constraint to production. Fruit and vegetable production opens up new markets for agricultural households, possibly leading to higher household income.

III.5 Model

We utilize a linear programming model to optimize net returns subject to constraints. The baseline form of the model maximizes the objective function with respect to land, labor, food security, and rotation constraints. The variable labels and constraint definitions are described below; a formal definition of the model can be found in Appendix B.

Table 3.1: Variables in Linear Programming Model

Label	Variable
PML	Produce Maize – Low Technology
PMM	Produce Maize – Medium Technology

PMH	Produce Maize – High Technology
PBL	Produce Beans – Low Technology
PBM	Produce Beans – Medium Technology
PBH	Produce Beans – High Technology
PTL	Produce Tomatoes – Low Technology
PTM	Produce Tomatoes – Medium Technology
PTH	Produce Tomatoes – High Technology
POL	Produce Onions – Low Technology
POM	Produce Onion – Medium Technology
POH	Produce Onion – High Technology
PPL	Produce Potatoes – Low Technology
PPM	Produce Potatoes – Medium Technology
PPH	Produce Potatoes – High Technology
RPML	Rotation – Produce Maize – Low Technology
RPMM	Rotation – Produce Maize – Medium Technology
RPMH	Rotation – Produce Maize – High Technology
CM	Consume Maize
CB	Consume Beans
SM	Sell Maize
SB	Sell Beans
ST	Sell Tomatoes
SO	Sell Onions
SP	Sell Potatoes
TM	Transport Maize
TB	Transport Beans
TT	Transport Tomatoes
TO	Transport Onions
TP	Transport Potatoes

Table 3.2: Constraints in Linear Programming Model	
Yield Transfer Rows	Maize Yield Transfer
	Beans Yield Transfer
	Tomato Yield Transfer
	Onion Yield Transfer
	Potato Yield Transfer
Land Constraint	Land
Labor Constraints	April Labor
	May Labor
	June Labor
	July Labor
	August Labor
	September Labor
Transport Transfer Rows	Maize Transport Transfer
	Beans Transport Transfer
	Tomato Transport Transfer
	Onion Transport Transfer
	Potato Transport Transfer
Food Security Constraints	Maize Food Security
	Beans Food Security
Rotation Constraints	Rotation Tomatoes with Maize (T:M)
	Rotation Potatoes with Onions (P:O)
	Rotation Maize with Beans (M:B)

We select five crops to include in the model at three technology levels each. These 15 crop activities are represented as costs in the linear programming objective function. The three technology levels represent different intensities of IPM use. We also include the revenue from each of the five crops, represented as selling activities in the model; the objective function maximizes the difference between the revenues and the costs of production subject to the constraints. Household consumption is included in the model as a constraint to account for the amount of maize and beans the household is consuming and not selling. Distance to market is reflected through the transportation activities; as distance to market increases, the cost of transporting the crops to market increases.

The model relies on several assumptions. First, we assume that there is no substitution of inputs and there are constant returns to scale. Second, we assume that prices are fixed and taken by the farmer and that farmers operate with the objective of maximizing profit. Third, we assume that the household is restricted to the production of the five crops listed in Table 3.1. This assumption is reasonable because we are interested in the decision making of small, poor households that probably do not have a wide variety of choice of crops. Also, geographically speaking there is a limited number of crops that can be produced in any one area of Honduras. In terms of sale of crops, we assume that the household sells all its vegetables. In reality, the farm may retain a small portion of this product for their own consumption, but on the whole we do not expect many households to invest in vegetable production if their main purpose is not to sell vegetables in the market. This is not a critical assumption, as we could add vegetables to the consumption constraint and not much would change. We assume no land rental market. Labor is initially constrained to that which the family can provide, but we later relax this constraint.

We subject the model to several scenarios. We first run the baseline model (see Appendix) including the land, labor, rotation and consumption constraints. Then, we alter the model to reflect five scenarios. These scenarios test model sensitivity and make our analysis more realistic. In these additional scenarios we vary distance to the output market, vary distance to the input market, adjust and relax the food security constraint, allow the household to hire in labor, and restrict the household to one technology level per crop.

III.6 Data

Data come from a variety of sources, including production budgets, interviews with farmers, extension agents, agricultural professionals, and a 2007 survey of living conditions in the Trifinio region of Central America (International Food Policy Research Institute and Plan Trifinio). A big assumption is that the data from the survey of the Trifinio region is representative of agricultural households in Honduras. Information from these sources is extracted and combined to create a linear programming model of a representative Honduran farm. This model contains information on production costs for five crops, at three levels of technology for each crop. The five crops included in the analysis are: maize, beans, tomato, onion, and potato. These crops were selected based on information availability as well as based on their ability to be grown in the same geographic area.

Specifically, the production cost for each crop activity equals:

$$\begin{aligned}\sum & soil\ preparation\ cost + soil\ preparation\ labor\ cost + seed\ and\ planting\ cost + planting\ labor\ cost \\ & + fertilizer\ cost + fertilizer\ application\ labor\ cost + pesticide\ and\ fungicide\ cost \\ & + pesticide\ and\ fungicide\ labor\ cost + herbicide\ cost \\ & + herbicide\ application\ labor\ cost + irrigation\ cost + irrigation\ labor\ cost \\ & + harvest\ cost + harvest\ labor\ cost\end{aligned}$$

Each of these cost factors can vary with the level of technology. The production cost coefficients are listed in Table 3.3 together with objective function coefficients for consumption, sales, and transportation activities. Coefficients for the consumption activities are zero; the farm does not receive any revenue from this production. Sales activity coefficients are the average selling price from the Fintrac and PROMIPAC production budgets. Coefficients for the transportation activities are based on expert opinion and are detailed in Table 3.5.

Table 3.3 : Objective Function Coefficients	
Variable	Objective Function Coefficient
PML	-519.95
PMM	-1116.14
PMH	-1470.97
PBL	-392.16
PBM	-382.43
PBH	-1128.64
PTL	-3762.8
PTM	-10841.71
PTH	-9753.42
POL	-5161.53
POM	-5538.15
POH	-6262.39
PPL	-3491.22
PPM	-3634.04
PPH	-5070.17
RPML	-519.95
RPMM	-1116.14
RPMH	-1470.97
CM	0
CB	0
SM	0.26
SB	0.30
ST	0.22
SO	0.18
SP	0.16
TM	-(0.0013)(x[5])
TB	-(0.0013)(x)
TT	-(0.003)(x)
TO	-(0.0025)(x)
TP	-(0.002)(x)

Labor requirements for each crop activity are included in the model as constraints, and are recorded in person days/manzana/month. The labor requirements are based on Fintrac production budgets. The rainy season is from May to September, and therefore labor requirements are for the six month period (April to September) when work is occurring for this planting season (see Table 3.4). The average number of workers in the household is also an

[5] Where x = number of miles from the market

important piece of data, as we are interested in seeing how labor supply affects production decisions. For the purposes of the baseline model, the household does not hire in any additional labor. Taken from the IFPRI Trifinio survey, four workers on average per household is the number used in the model. This is reflected on the right hand side of the labor constraints, as the total number of person days available per month for work on the farm. As an example of, the labor requirement for low-technology maize for the month of April is:

$$\sum_{days} PML\ April = \ soil\ preparation\ labor + planting\ labor + fertilizer\ application\ labor + pesticide\ and\ herbicide\ labor + fungicide\ labor + irrigation\ labor + harvest\ labor$$

Table 3.4: Labor Requirements by Crop Activity[6] (Person Days/Manzana)

	April	May	June	July	August	September
PML	0	25	3	3	0	18
PMM	0	13.32	5.32	5.32	0	23
PMH	8.64	23.32	10.72	10.72	10.72	26.5
PBL	2	17.26	9.26	7.26	1.815	32
PBM	1	28	20	20	0	19
PBH	0	14.43	11.28	8.68	0.88	16
PTL	0	34.44	18.44	19.44	18.44	99.22
PTM	288	109.83	29.83	27.16	27.16	267.58
PTH	0	64.94	24.94	20.44	20.44	263.85
POL	120	46	46	46	40	0
POM	7	18	16	20	100	0
POH	17	136.38	50.71	25.84	100	0
PPL	36	56.16	40.16	40.16	64	0
PPM	48.39	30.2	22.2	22.2	25	0
PPH	17.99	28.67	19.34	12	25	0

[6] Based on Fintrac Production Budgets, 2011

Information on rotation requirements is important in order to make the model realistic; for this model we choose to require maize to be rotated with beans, maize to be rotated with tomatoes, and potatoes to be rotated with onion (FAO, 2011). Food security information is another important piece of the model; in this case we look at the consumption information contained in the IFPRI Trifinio survey as well as two reports on grain markets and poverty (Minot and Goletti, 2000; Walker, 1984) and estimate that for an average household size of 6 people, a household needs 990 pounds of maize and 742.5 pounds of beans in order to have enough of these staples for consumption in the following season. However, households close to the market may not face food security concerns due to their location, and we will study how this impacts crop choice in the linear programming analysis.

Transportation costs for the five crops were obtained through expert opinion and are detailed in Table 3.5. Cost per truckload for staple crops is estimated at $1.31/mile; transportation cost for perishable crops is estimated at $2.00/mile, with particularly sensitive vegetables (i.e. tomatoes and onions) having an additional transportation premium. As an example, the cost of transporting one pound of maize one mile ($0.00131) is calculated by dividing $1.31 by 1000 (the average amount a small pick-up truck can transport to the market). The transportation costs will be analyzed for sensitivity later in this analysis.

Table 3.5: Transportation Costs by Crop

Crop	Transportation Cost	$/truckload/mile	$/pound/mile
Maize	base value for staple crops	1.31	.0013
Beans	base value for staple crops	1.31	.0013
Tomato	base value for vegetables plus 50%	2.00 + (2.00)(.50) = 3.00	.003
Onion	base value for vegetables + 25% premium	2.00 + (2.00)(.25) = 2.50	.0025
Potato	base value for vegetables	2.00	.002

The definitions of low-technology, medium-technology and high-technology are slightly different for each crop. Low-technology and medium-technology information was obtained through PROMIPAC- an IPM extension agency housed at Zamorano University. PROMIPAC retains budgets for farmers at different levels of IPM use; they check-in with their farmers several times a year to collect production data. The high-technology crop activities in this model are based on production budgets from Fintrac and represent a farm using Fintrac's recommended IPM package. A farm following a Fintrac production budget has a high degree of access to inputs, as well as the financial resources to implement multiple IPM practices at once. Specific technologies utilized for each crop activity are outlined in Table 3.6.

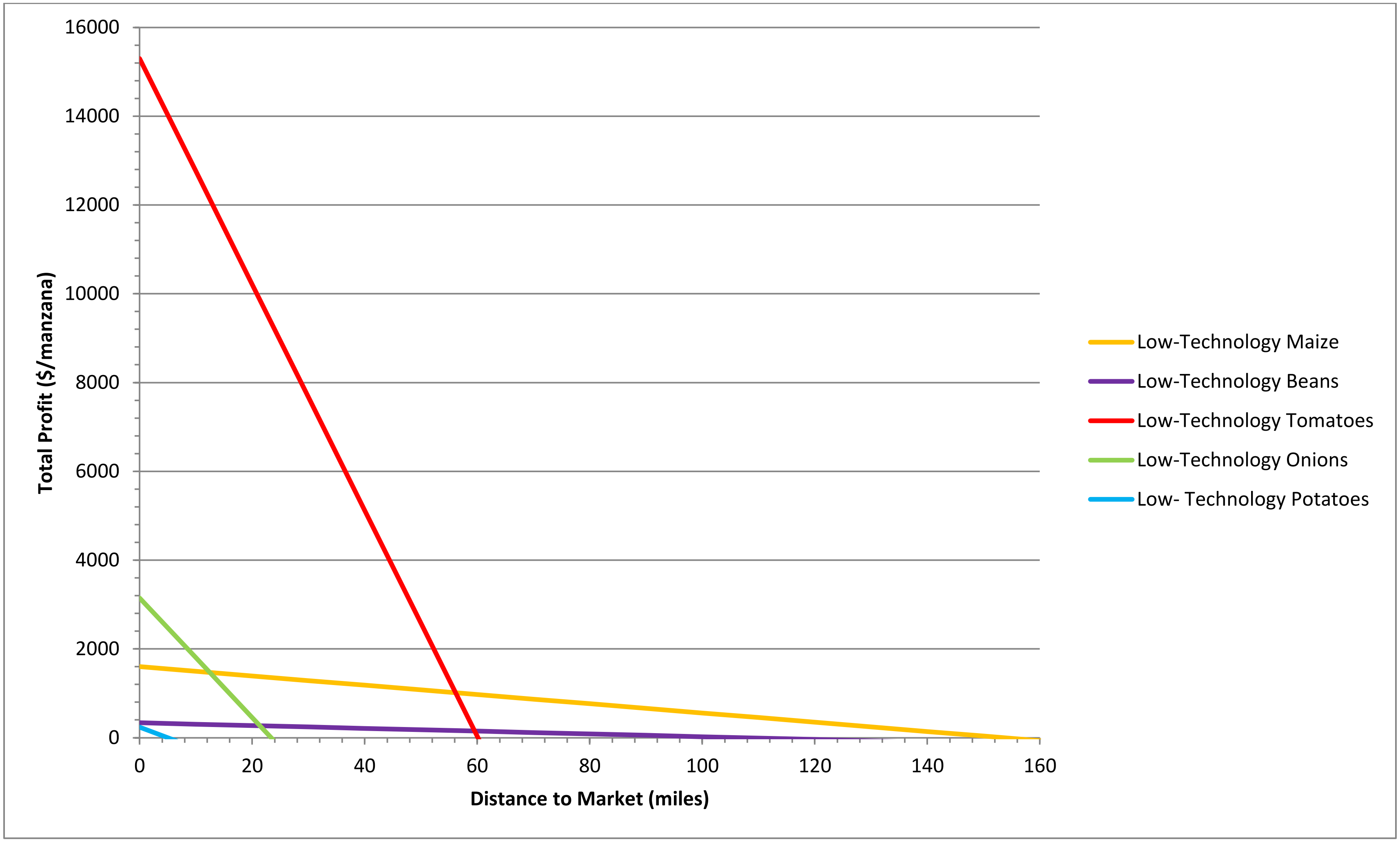
Table 3.6: Technology Level Descriptions by Crop			
	Low-Technology	Medium-Technology	High-Technology (Fintrac recommended package - includes some or all)
Maize	Rain irrigation Basic fertilizer and pesticides	Improved fertilizer application Scouting Enhanced seed varieties	Drip or mechanized irrigation Covered production Soluble fertilizer Reduced application of chemicals Natural enemies Border crops Raised beds
Beans	Rain irrigation Basic fertilizer and pesticides	Improved fertilizer application Scouting Enhanced seed varieties	Drip or mechanized irrigation Covered production Soluble fertilizer Reduced application of chemicals Natural enemies Border crops Raised beds
Tomato	Rain irrigation Basic fertilizer and pesticides	Raised beds Soluble fertilizer Drip irrigation Natural barriers	Drip or mechanized irrigation Covered production Soluble fertilizer Reduced application of chemicals Natural enemies Border crops Raised beds
Onion	Rain irrigation Basic fertilizer and pesticides	Reduced pesticide and fungicide application Soluble fertilizer Drip irrigation Raised beds	Drip or mechanized irrigation Covered production Soluble fertilizer Reduced application of chemicals Natural enemies Border crops Raised beds
Potato	Rain irrigation Basic fertilizer and pesticides	Raised beds Biological controls Soluble fertilizer Improved spraying techniques	Drip or mechanized irrigation Covered production Soluble fertilizer Reduced application of chemicals Natural enemies Border crops Raised beds

Utilizing the production cost, revenue, and transportation cost data for a representative Honduran farm household, we algebraically determine the distance at which each crop activity in the linear programming model results in \$0 profit for the farm. This is done by setting net profit equal to 0 in the equation below and solving for distance.

$$\begin{aligned} Net\ profit\ (\$) \\ &= revenue\ per\ lb(\$) - production\ cost\ per\ lb(\$) \\ &- (transportation\ cost\ per\ lb\ [\$])(distance\ in\ miles) \end{aligned}$$

We then plot the distance where each activity is no longer profitable against the total expected profit from the crop activity (based on yield data). Figure 5 displays this relationship for the low-technology crops and yields several important results. One, maize and beans production is profitable at much further distance than tomatoes, onions, or potatoes. This finding is expected, and follows von Thünen's theory outlined earlier in this paper. The furthest distance a vegetable crop is profitable is 60.14 miles. Low-technology tomatoes are profitable up until this point, but beyond it will not be selected by a profit-maximizing farm household. Therefore we expect that a farm household located more than 60.14 miles away will produce some combination of maize and beans and no vegetables. The probit model results from our econometric analysis coincide with this finding- in the probit model, a distance of 43.33 miles was determined to be the distance at which fruit and vegetable production is no longer profitable. Here, the distance is slightly farther (60.14 miles) but similar enough to conclude that the critical distance for fruit and vegetable production is around somewhere close to the 40-60 mile range. A graph similar to Figure 3.9 can be found in Appendix C that includes all 15 crop activities.

Figure 3.9: The Impact of Distance to Market on Profit[7]



[7] Calculated by setting net profit in the equation on page 79 equal to zero and solving for distance in miles

III.7 Results

Baseline model results are presented is first, followed by five scenarios where different parts of the model are adjusted. These scenarios make the model more realistic, as well as offer insight into the sensitivity of our model and how the crop mix changes given exogenous changes in the model coefficients.

III.7.1 Baseline Model

The baseline model for this analysis is outlined in detail in the appendix. It includes all the activities from Table 3.1 and all the constraints from Table 3.2. Results are reported for an agricultural household 10 miles from the market and an agricultural household 30 miles from the market.

Table 3.7: Baseline Model Results				
Distance from Market	10 Miles		30 Miles	
Crop Activity	Value	Reduced Cost	Value	Reduced Cost
PML	0.98	0	0.98	0
PMM	0	154.19	0	85.68
PMH	0	1,839.44	0	885.63
PBL	0	2,204.7	0	1,156.95
PBM	0	957.01	0	393.35
PBH	0.16	0	0.16	0
PTL	0.98	0	0.98	0
PTM	0	20,648.04	0	15,435.96
PTH	0	13,947.15	0	10,682.14
POL	0	7,276.17	0	6,150.03
POM	0.99	0	0.95	0
POH	0	18.161.74	0	12,536.74
PPL	0	10,016.74	0	5,904.86
PPM	0	103.87	0.95	0
PPH	0.99	0	0	336.13
RPML	0.16	0	0.16	0
RPMM	0	154.19	0	85.68
RPMH	0	1,839.44	0	885.63
CM	989.01	0	988.96	0
CB	742.33	0	742.33	0
SM	8,137.79	0	8,137.79	0
SB	0	0.3513	0	0.16
ST	82,948.77	0	82,948.78	0
SO	139,735	0	139,735	0
SP	47,425.21	0	38,109.54	0
TM	9,126.65	0	9,126.65	0
TB	742.33	0	742.33	0
TT	82,498.77	0	82,948.78	0
TO	139,735	0	139,735	0
TP	47,425.21	0	38,109.54	0
Net Returns/ Household Member ($)	5,435.05		3,129.4	

Results indicate that a profit-maximizing farm 10 miles from the market will produce about 1 manzana of low-technology maize rotated with 1 manzana of low-technology tomatoes. The farm will also produce about 1 manzana of medium-technology onions with high-technology potatoes. A small amount of high-technology beans (about 1/5 mz) will be produced and rotated with low-technology maize. At these levels of production, the net returns per person in the households are $5,435.05. When the distance to market is increased to 30 miles, the crop mix remains similar, with one major change. About 1 manzana of low-technology maize is rotated with 1 manzana of low-technology tomatoes and a small area of high-technology beans is rotated with low-technology maize. At this distance however, instead of high-technology potatoes, medium-technology potatoes are being produced also with medium-technology onions. The net return per household member decreases significantly to $3,129.4 (a percentage decrease of 45.59). The change in net returns per household member is driven by the increase in transportation costs due to the increase in distance to the output market (from 10 to 30 miles).

For the 10 mile from the market baseline model, shadow prices for the labor constraints tell us the amount by which the objective function value would change given a one-unit increase in the amount of family labor available. For example, relaxing the April labor constraint by one day would increase our objective function value by $95.17. Later in Scenario 3 we relax the labor constraints by allowing the farm to hire in labor and report the results. We expect that profit will be higher, holding all else constant, when the farm is able to hire in labor.

III.7.2 Scenario 1 – Vary Distance to the Output Market

In Scenario 1, we take the baseline model and vary distance to the output market from 10 miles to 100 miles. This change in distance is reflected through increases in the transportation costs to market. We expect the crop mix to change; specifically, we expect fruit and vegetable production to decrease and staple crop production to increase as distance to market increases. We anticipate a distance at which fruit and vegetable production will cease. We expect net returns per household member to decrease as distance to the output market increases.

Table 3.8: Variable Distance to Output Market		
Distance to Market (miles)	Crop Mix (manzanas)	% Change in Net Returns per Household Member (from previous distance)
10	0.98 PML 0.16 PBH 0.98 PTL 0.98 POM 0.99 PPH 0.16 RPML	-
20	0.98 PML 0.16 PBH 0.98 PTL 0.95 POM 0.95 PPM 0.16 RPML	-21.35
30	0.98 PML 0.16 PBH 0.98 PTL 0.95 POM 0.95 PPM 0.16 RPML	-26.80
40	0.98 PML 0.16 PBH 0.98 PTL 0.85 POM 0.85 PPM 0.16 RPML	-59.27
50	0.34 PMH 1.81 PBH 0.34 PTL 0.77 POM 0.77 PPM 1.81 RPMH	-29.88
60	1.6 PBM 1.11 PBH 2.71 RPMH	-42.83
70	0.45 PBL 2.06 PBM 2.51 RPMH	-19.65
80	0.45 PBL 2.06 PBM 2.51 RPMH	-23.25
90	0.45 PBL 2.06 PBM 2.51 RPMH	-30.30
100	1.63 PBL 1.04 PBM 2.67 RPML	-33.69

Results indicate that vegetable production ceases somewhere between 50 and 60 miles from the market. In fact, the critical distance in this model is 55 miles; at 54 miles, vegetable production occurs, and at 55 miles the production of tomatoes, onions, and potatoes cease. At 55 miles and farther from the market, the household produces only maize and beans. This finding is consistent with our expectation and the results from our econometric analysis (critical distance of 43.33 miles). Net returns decrease significantly from $5,435.05 per household member when the household is 10 miles away to $874.06 per household member when the household is 100 miles away. The decrease in net returns is due to both the increase in transportation costs and the elimination of vegetables from the crop mix.

Distance to the output market is critical to both crop mix and household well-being. For households 54 miles from the output market and closer, the crop mix consists of a variety of vegetables and staple crops. Staple crops are produced both for own household consumption and sale at the market, and vegetable crops are produced and sold at the market for income. For households 55 miles from the output market and farther, the crop mix is limited to the production of maize and beans and income is drastically lower. Households far from the market have fewer production and marketing opportunities than households close to the market, which negatively impacts their well-being. Additionally, households relatively close to the market are more likely to benefit from knowledge of IPM practices and technologies, as they are already producing vegetables. The net profit of input-intensive vegetable production is often increased when IPM tactics are employed, meaning closer farms have more to gain from IPM than farther farms. Far farms may benefit some from IPM knowledge, however here the focus would be on staple crops such as maize and beans, which are less input intensive than vegetables to begin with. IPM programs that focus on vegetable production practices should focus on those farms relatively close to the market, as these are the farms which will gain the most from new and improved technologies.

III.7.3 Scenario 2 – Vary Distance to Input Market

In the second scenario we vary distance to the input market. In this scenario, distance to the output market is fixed at10 miles, but distance to the input market will increase. Under this scenario we assume that the two types of markets are located in different areas (this is feasible in Honduras). A change in distance to the input market is reflected through increases in the total production cost of each crop activity. To calculate the amount of this increase, we focus on the pesticide market. We increase the pesticide cost for each crop activity by $1.31 per mile from the input market. We estimate the cost to transport a truckload of pesticides to be the same as the cost to transport a truckload of a staple crop, because pesticides are neither perishable nor very sensitive to poor roads. Distance from the input market thus increases the cost of producing high-technology crops. Holding all else constant, an IPM program on a far farm will be relatively more expensive than an IPM program on a farm close to the input market. Distance from the input market may also increase the relative costs of an IPM program because it will be more expensive to learn about new IPM practices and obtain those inputs. However IPM programs generally use fewer inputs, making distance to the input markets less of a constraint for obtaining the physical inputs of production. Thus IPM may make vegetable production less risky for farms far from input and credit markets. We run the linear programming model with the new crop activity objective function values and report the results in Table 3.9.

Table 3.9: Variable Distance to Input Market																			
		Crop Mix																	
Distance to input market	% change in net returns	PML	PMM	PMH	PBL	PBM	PBH	PTL	PTM	PTH	POL	POM	POH	PPL	PPM	PPH	RPML	RPMM	RPMH
10	-	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
20	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.8	0	0	0	0.8	0.16	0	0
30	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
40	-0.001	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
50	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
60	-0.001	0.98	0	0	0	0	0.16	0.98	0	0	0	0.86	0	0	0	0.86	0.16	0	0
70	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
80	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
90	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0
100	-0.002	0.98	0	0	0	0	0.16	0.98	0	0	0	0.99	0	0	0	0.99	0.16	0	0

The results in Table 3.9 suggest that the crop mix is insensitive to changes in distance to the input market. The crop mix remains pretty much the same whether the pesticide market is 10 miles or 100 miles away. The net return per household member decreases as expected but does so at a very slow rate. To further examine this scenario, we double the pesticide transportation cost to two truckloads instead of one for the vegetable crops. It is feasible that staple crops may only require one truckload of pesticides while fruits and vegetables require more. When the model is run with these proportionately higher transportation costs for vegetable pesticides, we still observe results similar to those reported in Table 3.9.

For this model, distance affects production mainly through its impact on access to output markets. This is reasonable as the weight of the outputs dwarfs the weight of the inputs in our model. Purchased inputs are a small portion of total production costs. It is distance to the output market rather than distance to the input market that drives changes in crop mix and income. We expect distance to the input market and distance to the output market to vary together, with far away households facing both more expensive inputs and lower effective prices for their product. The crop mix is not sensitive to distance to the input market, but this may be due to underestimation of the transportation cost of inputs. With better information about the cost of obtaining inputs, we expect distance to the input market to impact the crop and technology mix. However, distance to the output market is the more important factor in our research.

III.7.4 Scenario 3 –Labor Market

In our baseline model, we assume that the household is not hiring any off-farm labor for work on the farm. This may be the case for some agricultural households in Honduras, but many do participate in the labor market in addition to utilizing family labor. Households close to a central market may be more inclined to participate in the labor market as these households are easier for workers to travel to and the area where they live has a higher population density (more potential workers). Households far from a central market may be less likely to participate in the labor market. Workers must travel to the farm, and the wage must be high enough to entice the worker to travel the distance to the farm. Additionally, far farms are likely located in areas with lower population densities, meaning fewer potential workers for hire. In Scenario 3 we incorporate labor activities into the model and analyze how the crop mix and net returns per household member are affected. In this scenario, the household can hire in unlimited quantities of labor at a daily wage of $8.00 a day, a figure based on both Fintrac's production budgets and expert opinion. We then vary the wage to a low of $5.00 a day and a high of $11.00 a day. Results with labor market participation are summarized in Table 3.10.

Table 3.10: Hire In Labor

Activity	Wage: $8.00/day	Wage: $5.00/day	Wage: $11.00/day
PML	0	0	0
PMM	0	0	0
PMH	0	0	0
PBL	0	0	0
PBM	0	0	0
PBH	0.16	0.16	0.16
PTL	0	0	0
PTM	0	0	0
PTH	0	0.17	0
POL	0	0	0
POM	3.41	3.41	3.41
POH	0	0	0
PPL	0	0	0
PPM	0	0	0
PPH	3.41	3.41	3.41
RPML	0	0	0
RPMM	0	0	0
RPMH	0.16	0.16	0.16
April	0	0	0

Labor			
May Labor	41.37	46.49	41.37
June Labor	4.14	5.23	4.14
July Labor	0	0	0
August Labor	304.17	304.5	304.17
September Labor	0	0	0
Net Returns/ Household Member	$12,484.27	$12,685.39	$12,309.42

When the household is no longer restricted to the labor household members can provide, it increases the total amount of land devoted to vegetable production substantially. Vegetables, while highly profitable, are also very labor-intensive. The relaxation of the labor constraint by allowing labor to be hired in has a significant impact on vegetable production. When the daily wage is $8.00 a day, the household produces relatively large amounts of medium-technology onions and high-technology potatoes, as well as a small amount of maize and beans to satisfy the food security constraints. The same crop mix is selected when the wage is increased to $11.00 a day. When the wage is lowered to $5.00 a day, a small amount of low-technology tomatoes is farmed in addition to the medium-technology onions and high-technology potatoes. Net returns per household member increase as the labor wage decreases, reflecting the lower total cost of production as labor costs decrease. The net returns reported in Table 3.10 are very high, and we assume that a household producing at this level has the skill to successfully recruit and manage such high amounts of labor, as well as the cash on hand to pay laborers for their time. Many small farms in Honduras do not have the access to credit required to borrow money to pay laborers, and therefore may be unable to hire in such a large amount of labor. The ability to hire in labor at a market wage is important to the production of vegetables, as these crops typically have higher labor requirements than staple crops.

Shadow prices for the labor constraints in Scenario 3 offer important information about the impact of labor market participation on production. At a wage of $8.00/day, the household is hiring in labor for May, June and August, however the constraints for the months of April, July, and September are binding. Relaxing the April labor constraint by one unit would increase our objective function value by $33.36. September is a particularly labor intensive month, as this is when some harvesting occurs- a one unit increase in the amount of labor available in September would increase the objective function value by $112.99. Relatively close households will be more likely to take advantage of the benefits of hiring in an additional unit of labor as they have greater access to the labor market. Far households will be less likely to hire in additional units of labor as they have fewer workers at their disposable and are typically producing less labor intensive staple crops.

III.7.5 Scenario 4 – Vary Food Security Needs

Food security is critical in most developing countries and Honduras is no exception. In this scenario we both remove the food security concerns and increase the food security requirements. The first column of results in Table 3.11 is for a close farm (10 miles from the market) that is assumed not to be constrained by food security concerns because they can purchase any crops they need for consumption at market. The second column of results is for a distant farm that faces very high food security concerns (double that of the baseline model). This type of farm is likely located farther from the market; in Table 3.11, the farm with high food security requirements is assumed to be 60 miles away from the market.

Table 3.11: Food Security					
Crop Mix	Baseline Model 10 Miles from Market	No Food Security Requirements 10 Miles from Market	Baseline Model 60 Miles from Market	No Food Security Requirements 60 Miles from Market	High Food Security Requirements 60 Miles from Market
PML	0.98	1.02	0	0	0
PMM	0	0	0	0	0
PMH	0	0	0	0	0
PBL	0	0	0	0	0
PBM	0	0	1.6	1.6	1.6
PBH	0.16	0	1.11	1.11	1.11
PTL	0.98	1.02	0	0	0
PTM	0	0	0	0	0
PTH	0	0	0	0	0
POL	0	0	0	0	0
POM	0.99	0.99	0	0	0
POH	0	0	0	0	0
PPL	0	0	0	0	0
PPM	0	0	0	0	0
PPH	0.99	0.99	0	0	0
RPML	0.16	0	0	0	0
RPMM	0	0	0	0	0
RPMH	0	0	2.71	2.71	2.71
Net Returns/ Household Member	$5,435.05	$5,558.50	$511.04	$590.82	$431.02

An agricultural household close to the market with no food security concerns will produce low-technology tomatoes rotated with low-technology maize, and medium-technology onions rotated with high-technology potatoes. This type of household will produce no beans, and the maize is only produced as a compliment to the tomato production. A household close to the market but with food security concerns will produce slightly less tomatoes and slightly more maize and beans. The household with food security concerns devotes a slightly smaller portion of their land to the production of vegetables, as expected. Net returns per household member for a household with no food security concerns are $5,558.50, slightly higher than the $5,434.05/household member we observed in the baseline model.

For the household that is 60 miles away from the market with food security concerns, maize and beans are produced- some of the product is being consumed and some is being sold. A household that is the same distance from the market but with no food security concerns will produce the same amount of maize and beans, and will have slightly higher net returns/household member ($590.82 as compared to $511.04). When food security requirements are especially high (double that of the baseline model), a household still selects only maize and beans for production. This is due to a combination of the large amount of maize and beans required for consumption and the high transportation costs of crops when a household is far from the market. Net returns per household member are lower for a household with high food security requirements- $431.02, compared to for the household with the baseline food security requirements, $511.04.

For households relatively close the market, we expect food security to be less of a concern. These household have better access to markets for all types of crops, and can likely purchase any product they may need for consumption. For close households that do have some food security concerns, they will devote slightly smaller amounts of land to the production of vegetables but not a significant amount. Household that are relatively farther away from the market are much more likely to face food security concerns. However, these same household are also already likely to be producing large quantities of staple crops. The crop mix therefore does not change very much as food security requirements increase- rather the net returns per household member reflect the additional units of maize and beans that are being consumed rather than being sold at market.

III.7.6 Scenario 5 – Prohibit Multiple Technology Levels for Same Crop

In the baseline model and the previous scenarios we sometimes observe households selecting multiple technology levels of the same crop. For example, in some models a household selects both low-technology and medium-technology beans. It is more likely that a farm household will not utilize one technology level on one portion of land and another on a different portion of land for the same crop. However, there may be a few cases where this occurs. For example, a risk-mitigating strategy might be to devote a small portion of land to production with a new technology while the majority of the crop is produced with a familiar technology. This way if there are problems with the new technology the household is not completely without crop for consumption or sales. Additionally, access to credit is important for the adoption of technologies. If a farm has limited access to credit, they may adopt a technology for a portion of their production but not for the entire plot. When learning how to successfully implement a production technology, a farmer may focus the new practice on a portion of land instead of the entire area, as success may take time.

In the long-run it would be costly and complicated for a farm household to maintain different technology levels for the same crop. In our analysis, the selection of two different technology levels for the same crop occurs in the models of the relatively far households (60-100 miles) from Scenario 1 and in the model of high food security concerns from Scenario 4. In Scenario 5 we note the crop activity that is produced in the highest quantity and restrict the other two technology levels to zero. This forces the model to select only 1 technology level for each crop. Results are reported in Table 3.12.

Table 3.12: Prohibit Multiple Technology Levels for the Same Crop						
Crop Activity	Baseline Model – 60 Miles from Market	Baseline Model – 70 Miles from Market	Baseline Model – 80 Miles from Market	Baseline Model – 90 Miles from Market	Baseline Model – 100 Miles from Market	High Food Security Requirements – 60 Miles from Market
PML	0	0	0	0	0	0
PMM	0	0	0	0	0	0
PMH	0	0	0	0	0	0
PBL	0	0	0	0	0	0
PBM	2.42	2.42	2.42	2.42	2.42	2.42
PBH	0	0	0	0	0	0
PTL	0	0	0	0	0	0
PTM	0	0	0	0	0	0
PTH	0	0	0	0	0	0
POL	0	0	0	0	0	0
POM	0	0	0	0	0	0
POH	0	0	0	0	0	0
PPL	0	0	0	0	0	0
PPM	0	0	0	0	0	0
PPH	0	0	0	0	0	0
RPML	0	0	0	0	0	0
RPMM	0	0	0	0	0	0
RPMH	2.42	2.42	2.42	2.42	2.42	2.42
Net Returns/ Household Member	$478.61	$387.07	$295.53	$203.98	$112.44	$398.59

For the models included in this scenario, both medium and high technology beans are selected at first. When high-technology and low-technology beans are restricted to zero, the solution shifts some of the high-technology bean production to medium-technology bean production, but overall the amount of bean production decreases from 2.71 to 2.42 manzanas. Subsequently, the amount of maize production decreases as these two crops are being produced in rotation. Net returns per household member still decreases as distance to market increases, as expected. The 60-mile from market baseline model has higher net returns per household member than the 60-mile from market high food security model due to a greater proportion of the staple crops being consumed in the high food security model. Scenario 5 tells us that when households are restricted to just one technology level per crop, the crop mix does not change; instead the production shifts from one technology level to the other. When production of a crop is restricted to one technology level, total production of that crop decreases, albeit only slightly. We conclude that over time a Honduran farm will converge on one technology level for all crops.

In the preceding scenarios we took our baseline linear programming model and modified it to account for a variety of changes to the production process and production costs. We find that the crop mix selected by Honduran farmers is more sensitive to changes in distance to the output market than changes in distance to the input market. We also note that when food security is not a concern for Honduran farms they devote more of their land to the production of vegetables as compared to households with food security concerns. Additionally, results show that when the Honduran household can hire in labor, the production of vegetables increases. The restriction of the crop mix to just one technology level per crop does not do much to change the crop mix; it merely reduces the total amount of land used for staple crop production which leads to slightly lower net returns per household member.

III.8 Conclusions

The results of this linear programming analysis support the conceptual framework outlined in this paper as well as our prediction about the relationship between distance and the production of perishables. There is a distance beyond which the production of fruits and vegetable is no longer profitable, and it is a reasonable expectation that beyond that distance virtually no fruit and vegetable production will occur. Evidence from our algebraic interpretation predicted this distance to be 60.14 miles, a previous econometric model predicted that distance to be 43.33 miles, and in the linear programming model fruit and vegetable production ceases at 55 miles from the market. Due to our additional constraints (rotation, food security, labor) vegetable production in the linear programming ceases slightly sooner than predicted. Resources are limited, and it is after 55 miles that our baseline model household elects to produce only staple crops. Maize and beans production still occurs beyond 55 miles from market.

Another conclusion from this study is that the profit-maximizing Honduran farm selects a combination of technology levels when deciding which crops to produce. In all three models reported here, there is a combination of low, medium, and high-technology crop activities selected. This is analogous to the stepwise procedure outlined by Byerlee and Hesse de Polanco; households typically cannot adopt entire integrated pest management packages at once and instead make small changes to their production processes over time. It would be prohibitively expensive for a Honduran farm household like the one outlined in this model to produce all crops with high-technology processes; instead they may adopt one or several integrated pest management practices at a time for one or several crops, but not all. However, in a long-term equilibrium (which this model is supposed to reflect) we would expect a farm to employ the same technology level for all its crops. High-technology production strategies are expensive to adopt, but we would expect that a farm would utilize such technology on their entire farm once they have invested money into the practices due to improved yields and higher net returns. We expect a long-term equilibrium to settle on one level of technology for all crops, be it low, medium or high.

Additionally, both the close and the distant farm select some medium and/or high-technology crop activities. The distant farm produces maize and beans only, but medium and high-technology beans and the high-technology maize are the most profitable. This may have to do with the notion that farms farther from the market have reduced access to input markets and therefore benefit from production practices that use fewer inputs (as IPM practices sometimes do). However, information access likely varies with distance to market- distant farms have less access to information about IPM, making IPM technologies less common the farther the farm is from the market. High-technology IPM strategies may thus also be less likely to be utilized the farther a farm is from the market. Typically, IPM information comes through access to model farms or farmer field days, pamphlets and paper materials, and interaction with other farmers, and far farms by nature of their location have less access to these information venues.

The amount of labor available in the model restricts selected crop activities; a high-technology production process may have a significantly higher labor requirement (as is the case for tomatoes) and thus these crop activities may be selected if the labor constraint is relaxed to allow the household to hire in labor. In Scenario 3 we allow the household to hire in labor, and observe both an increase in the total land devoted to vegetable production and the selection of medium or high-technology crop activities. Medium and high-technology crop activities are more labor intensive in our model but relaxing the labor constraint to allow the household to hire in additional labor combats these high labor requirements.

The production costs, yields, and revenues reported in the Fintrac budgets utilized in this analysis are very high and unrealistic for small Honduran farms. These budgets are extremely optimistic given conditions in Honduras. A farm utilizing a Fintrac budget must have almost unlimited access to inputs, markets, and cash, and small Honduran farms do not have such access. However, we believe the relative differences between the high-technology Fintrac budgets and the low and medium-technology budgets are appropriate and consistent. The relative differences in production costs, yields, revenue and profit allow us to compare how the crop activities and technology levels are selected by a profit-maximizing farm household.

Distance to the market is an important determinant of the crop and technology mix for Honduran agricultural households. Our baseline model and subsequent scenarios offer insight into this relationship as well as the relationship between crop mix and other production factors.

III.8.1 Contributions and Policy Implications

The analysis conducted in this paper contributes to the limited body of work on the impact of distance on farm household's decisions, and to the general IPM literature. Results support the theory that distance impacts a farm household's production and consumption choices, specifically, that as distance to the market or central city increases, perishables production is less likely to take place. This study suggests that distance to input and output markets will affect adoption of IPM. It appears that both close and far farms may select higher technology crop activities, so while the impact of distance on technology selection is not clear, it is important to look further into this connection. Additionally, this paper contributes to the body of literature that utilizes linear programming to study farm household decision making, offering yet another example of how this method can be employed. Lastly, results from this study support our previous econometric analysis of the impact of distance on the likelihood of fruit and vegetable production in the same geographic region (Honduras and the Trifinio region of Central America). The data and results in the linear programming analysis support both the hypotheses and the results of the econometric analysis.

Several policy implications arise. It is critical for research, extension and development agencies to continue supporting the dissemination of IPM information, technologies and practices. Information access is essential, and these results support improvement in access for both close and far farm households, as even relatively far farms would select medium and high-technology crop activities given the option. Perhaps these agencies could look into improving far away farmers' access to events like farmer field schools and field days, as well as set up model farms further away from the central town so that these far farmers can visit them and learn. However, it is costly to reach distant producers and extension agencies must balance this cost with the benefits to the farmers that would take advantage of IPM techniques. For example, Fintrac typically works with vegetable farmers that are relatively close to the cities and towns. For their organization, reaching distant farmers could be cost prohibitive. Another tactic for reaching farmers regardless of their physical location could be focusing on practices that can be used for any crop (such as staple crops), not just higher-value fruits and vegetables. This way far away farmers who may only be producing maize and beans could still take advantage of the benefits of integrated pest management. In addition, building of new roads and improvement of existing roads is an important policy for the Honduran government to consider if it aims to increase the economic potential of rural areas. Better quality and more frequent roads will reduce travel time for Honduran farmers, and while physical location cannot be changed, a new road can change the route a farmer takes to the market and thus change the effective distance the farmer must travel to participate in the market.

III.8.2 Limitations of Study and Future Research

The limitations of this study are based in part on the data available and in part on the nature of linear programming analysis. The five crops included here were selected based on data availability and their geographically complimentary nature, but increasing the types of crops in the model could yield an alternate crop mix. There are a variety of other horticultural crops produced in Honduras including eggplant, lettuce, carrots as well as the cash crops coffee and bananas.

Transportation cost data is based on expert opinion in our model, and while we feel this data is appropriate, it would certainly be more accurate to collect data on transportation costs directly from farmers and aggregate it somehow- as an average across time or observations. Additionally, it may be interesting to look at how transportation costs differ across different methods of transportation. For example, in our model the farmer has his own truck and transports product to the market himself; however, there are many other methods of transportation including truck rental and self-delivery, truck rental and paying a driver, paying a middleman who uses his own truck, and sharing the cost of a truck rental and/or driver with neighbors. Different transport methods have different costs, and therefore the crop mix selected may differ.

Another way to improve our model and better analyze the differences between technology levels would be to focus on the same IPM practices for each crop. In our current model, low, medium and high-technology means something different for each of the five crops. It may be better to isolate the increase in total production cost due to implementation of a specific technology or practice. For example, we would like to know how production costs, labor requirements, yield and profit change when a farmer invests in a natural enemies strategy. We could then look at whether a profit-maximizing farm selects the crop activity with the new strategy or not and say something about the profitability of the new technology based on the distance from the household to the market. Currently, none of the extension and research agencies we worked with are collecting data on the costs and benefits of adopting specific IPM practices or technologies, but this would add another level of interest and reality to our current model.

CHAPTER IV: RESEARCH CONCLUSIONS

At the beginning of this thesis, we made several predictions about the impact of distance to market on agricultural households' crop and technology choices. First, we predicted that distance to market is a significant determinant of crop choice. We went further to say that as distance to market increases, the likelihood of fruit and vegetable production decreases and the likelihood of staple crop production increases. Also, we hypothesize that there is a critical distance from the market beyond which profitable fruit and vegetable production will cease. Households beyond this critical distance may produce staple crops for sale at the market. Technology access and use is predicted to be an important factor for both close and far farms, and far farms may select high-technology production activities over low-technology production activities when high-technology activities require less dependence on the input market. Technology (specifically, integrated pest management practices) will likely be adopted in a stepwise manner- over time, instead of all at once.

Based on the results detailed in the two analyses, our study leads us to several conclusions about the impact of distance to market on agricultural households in Honduras and the Trifinio region. As distance to the main road increases, the likelihood of fruit and vegetable production for sale in the market decreases. Households far from a main road are less likely to produce fruits and vegetables for sale and more likely to produce fruits and vegetables for their own consumption. This result follows Thünen's theory that expensive to transport crops will be produced close to the central city. Our econometric analysis also yields a result that encourages further research into the relationship between input access and perishables production- mainly, that the presence of an irrigation system is positively related to fruit and vegetable market participation. Several other factors, including the age and gender of the head of the household, affect the probability a household participates in the fruit and vegetable market. We should be mindful of such factors when measuring the impact of distance. Results from our linear programming analysis reveal that for our representative Honduran household, there is a specific distance beyond which fruit and vegetable production will not occur. Once vegetables are no longer profitable, the household will elect to produce staple crops for sale at market. Despite higher production costs, medium and high-technology crop activities are selected by both the relatively close and the relatively far farms, providing support for the continued dissemination of IPM technologies. Overall, our earlier hypotheses are supported by our results.

This research yields important results while prompting additional research questions. Other variables impact perishables production, but distance to the output market is the most significant. As IPM becomes more widespread in developing countries, it will be important to further analyze its impact on farmers, especially the most rural and isolated. For countries with high poverty rates, policies that encourage high-value fruit and vegetable production could work to bring some poor farmers out of their current situation. Developed countries continue to demand fruits and vegetables, and the export market is another opportunity for farmers to participate in the supply chain and increase their incomes. With policies that promote new and improved infrastructure, extension and research agency work, and increased access to better practices such as IPM, countries like Honduras can greatly improve the livelihoods of rural farmers and their families.

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Appendix A: Detailed Probit Results

Table A.1: Probit Regression of Independent Variables on *fveg*						
				Number of Observations = 165		
				LR chi2(8) = 27.35		
				Prob > chi2 = 0.0023		
Log likelihood = -83.009186				Pseudo R2 = 0.1414		
fveg	Coefficient	Std. Err.	z	P > |z|	[95% Conf. Interval]	
timemainrd	0.0013	0.0021	0.63	0.530	-0.0028	0.0055
rainfallmm	0.0007	0.0005	1.52	0.129	-0.0002	0.0016
altitude	-0.0002	0.0004	-0.46	0.643	-0.0009	0.0005
agehh	-0.0135	0.0451	-0.30	0.764	-0.1019	0.0748
agehh2	0.0001	0.0004	0.33	0.743	-0.0007	0.0010
totalmzfarmed	0.0214	0.0383	0.56	0.576	-0.0537	0.0966
irrigate	0.4543	0.3720	1.22	0.222	-0.2749	1.1834
honduras	0.9406***	0.3009	3.13	0.002	0.3508	1.5303
femalehh	0.0164	0.3290	0.05	0.960	-0.6283	0.6612
producerorg	0.2678	0.2673	1.00	0.316	-0.2560	0.7916
_cons	-2.16	1.3681	-1.58	0.114	-4.8414	0.5214
***p<0.01, **p<0.05, *p<0.1						

Table A.2: Marginal Effects (Dependent Variable: *fveg*)							
Marginal effects after probit:							
y = Pr(fveg) (predict)							
= .23118557							
variable	dy/dx	Std. Err.	z	P > |z|	[95% C. I.]		X
timemainrd	0.0004	0.0007	0.63	0.530	-0.0009	0.0017	45.6424
rainfallmm	0.0002	0.0001	1.55	0.121	-0.0001	0.0005	1465.22
altitude	-0.0001	0.0001	-0.46	0.644	-0.0003	0.0002	892.176
agehh	-0.0041	0.0137	-0.30	0.764	-0.0310	0.0228	48.6
agehh2	0.0000	0.0001	0.33	0.743	-0.0002	0.0003	2608.96
totalmzfarmed	0.0065	0.0117	0.56	0.576	-0.0164	0.0294	1.9886
irrigate*	0.1545	0.1371	1.13	0.260	-0.1142	0.4232	0.1030
honduras*	0.2687	0.0770	3.49	0.000	0.1178	0.4196	0.5697
femalehh*	0.0050	0.1010	0.05	0.960	-0.1930	0.2030	0.1515
producerorg*	0.0805	0.0792	1.02	0.309	-0.0746	0.2357	0.5576
(*) dy/dx is for the discrete change of dummy variable from 0 to 1							

Table A.3: Probit Regression of Independent Variables on *producefvegonly*						
				Number of Observations = 165		
				LR chi2(8) = 33.18		
				Prob > chi2 = 0.0003		
Log likelihood = -58.553455				Pseudo R2 = 0.2208		
fveg	Coefficient	Std. Err.	z	P > |z|	[95% Conf. Interval]	
timemainrd	0.0045*	0.0023	1.92	0.055	-0.0001	0.0091
rainfallmm	0.0008	0.0005	1.54	0.123	-0.0002	0.0019
altitude	-0.0008	0.0005	-1.61	0.107	-0.0017	0.0002
agehh	-0.1035**	0.0525	-1.97	0.049	-0.2064	-0.0005
agehh2	0.0010**	0.0005	2.08	0.037	0.0001	0.0020
totalmzfarmed	0.0892**	0.0399	2.24	0.025	0.0111	0.1674
irrigate	-0.7617	0.6957	-1.09	0.274	-2.1252	0.6018
honduras	0.8422**	0.3911	2.15	0.031	0.0757	1.6087
femalehh	0.2836	0.3760	0.75	0.451	-0.4534	1.0206
producerorg	0.1209	0.3382	0.36	0.721	-0.5420	0.7838
_cons	-0.2461	1.5892	-0.15	0.877	-3.3608	2.8686
***p<0.01, **p<0.05, *p<0.1						

Table A.4: Marginal Effects (Dependent Variable: *producefvegonly*)							
Marginal effects after probit:							
y = Pr(producefvegonly) (predict)							
= 0.11305824							
variable	dy/dx	Std. Err.	z	P > |z|	[95% C. I.]		X
timemainrd	0.0009	0.0005	1.87	0.062	-0.0000	0.0018	45.6424
rainfallmm	0.0002	0.0001	1.59	0.111	-0.0000	0.0004	1465.22
altitude	-0.0001	0.0001	-1.59	0.112	-0.0003	0.0000	892.176
agehh	-0.0198	0.0100	-1.98	0.048	-0.0395	-0.0002	48.6
agehh2	0.0002	0.0001	2.08	0.037	0.0000	0.0004	2608.96
totalmzfarmed	0.0171	0.0077	2.22	0.027	0.0020	0.0323	1.9886
irrigate*	-0.0997	0.0548	-1.82	0.069	-0.2071	0.0078	0.1030
honduras*	0.1527	0.0671	2.28	0.023	0.0212	0.2842	0.5697
femalehh*	0.0611	0.0898	0.68	0.496	-0.1149	0.2370	0.1515
producerorg*	0.0230	0.0640	0.36	0.719	-0.1025	0.1484	0.5576
(*) dy/dx is for the discrete change of dummy variable from 0 to 1							

Table A.5: Probit Regression of Independent Variables on ***prodandsoldfveg***						
				Number of Observations = 165		
				LR chi2(8) = 28.31		
				Prob > chi2 = 0.0016		
Log likelihood = -40.5752				Pseudo R2 = 0.2586		
fveg	Coefficient	Std. Err.	z	P > |z|	[95% Conf. Interval]	
timemainrd	-0.0052	0.0041	-1.26	0.208	-0.0133	0.0029
rainfallmm	0.0003	0.0006	0.49	0.625	-0.0010	0.0016
altitude	0.0005	0.0005	1.04	0.299	-0.0004	0.0014
agehh	0.1980*	0.1029	1.92	0.054	-0.0037	0.3996
agehh2	-0.0023*	0.0012	-1.93	0.053	-0.0045	0.0000
totalmzfarmed	-0.1705*	0.1197	-1.42	0.155	-0.4051	0.0642
irrigate	1.0019**	0.4583	2.19	0.029	0.1036	1.9001
honduras	0.4571	0.3915	1.17	0.243	-0.3103	1.2245
femalehh	-0.4476	0.4615	-0.97	0.332	-1.3521	0.4568
producerorg	0.2943	0.3519	0.84	0.403	-0.3955	0.9840
_cons	-6.2850***	2.3800	-2.64	0.008	-10.9497	-1.6203
***p<0.01, **p<0.05, *p<0.1						

Table A.6: Marginal Effects (Dependent Variable: ***prodandsoldfveg***)							
Marginal effects after probit:							
y = Pr(prodandsoldfveg) (predict)							
= 0.03755001							
variable	dy/dx	Std. Err.	z	P > |z|	[95% C. I.]		X
timemainrd	-0.0004	0.0004	-1.12	0.263	-0.0012	0.0003	45.6424
rainfallmm	0.0000	0.0001	0.49	0.628	-0.0001	0.0001	1465.22
altitude	0.0000	0.0000	0.95	0.344	-0.0000	0.0001	892.176
agehh	0.0162	0.0072	2.25	0.025	0.0021	0.0303	48.6
agehh2	-0.0002	0.0001	-2.44	0.015	-0.0003	-0.0000	2608.96
totalmzfarmed	-0.0140	0.0098	-1.43	0.154	-0.0331	0.0052	1.9886
irrigate*	0.1593	0.1120	1.42	0.155	-0.0603	0.3789	0.1030
honduras*	0.0360	0.0350	1.03	0.303	-0.0326	0.1046	0.5697
femalehh*	-0.0280	0.0243	-1.15	0.249	-0.0757	0.0196	0.1515
producerorg*	0.0236	0.0293	0.80	0.422	-0.0339	0.0810	0.5576
(*) dy/dx is for the discrete change of dummy variable from 0 to 1							

Appendix B: Baseline Linear Programming Model

This model maximizes the objective (profit) function:

(1) - 519.95PML - 1116.14PMM - 1470.97PMH - 392.16PBL - 382.43PBM
- 1128.64PBH - 3762.8PTL - 10841.71PTM - 9753.42PTH - 5161.53POL
- 5538.15POM - 6262.39POH - 3491.22PPL - 3634.04PPM - 5070.17PPH
- 519.95RPML - 1116.14RPMM - 1470.97RPMH + 0.26SM + 0.30SB + 0.22ST
+ 0.18SO + 0.16SP - (0.001306452)(X[8])TM - (0.001306452)(X)TB - (0.003)(X)TT
- (0.003)(X)TO - (0.002)(X)TP

Subject to:

Yield Transfer Rows:

(2) Maize: 8000PML + 11600PMM + 15400PMH + 8000RPML + 11600RPMM + 15400RPMH – 1CM – 1SM = 0
(3) Beans: 2400PBL + 2000PBM + 4500PBH – 1CB – 1SB = 0
(4) Tomato: 85000PTL + 101168PTM + 122500PTH – 1ST = 0
(5) Onion: 45000POL + 165000POM + 52500POH – 1SO = 0
(6) Potato: 24000PPL + 45000PPM + 56000PPH – 1SP = 0

Land Constraint:

(7) 1PML + 1PMM + 1PMH + 1PBL + 1PBM + 1PBH + 1PTL + 1PTM + 1PTH + 1POL + 1POM + 1POH + 1PPL + 1PPM + 1PPH + 1RPML + 1RPMM + 1 RPMH ≤ 7.15

Labor Constraints:

(8) April: 8.64PMH + 2PBL + 1PBM + 288PTM + 120POL + 2POM + 17POH + 36PPL + 48.39PPM + 17.99PPH + 8.64RPMH ≤ 120
(9) May: 25PML + 13.32PMM + 23.32PMH + 17.26PBL + 28PBM + 14.43PBH + 34.44PTL + 109.83PTM + 64.94PTH + 46POL + 18POM + 136.38POH + 56.16PPL + 30.2PPM + 28.67PPH + 25RPML + 13.32RPMM + 23.32RPMH ≤ 124
(10) June: 3PML + 5.32PMM + 10.72PMH + 9.26PBL + 20PBM + 11.28PBH + 18.44PTL + 29.83PTM + 24.94PTH + 46POL + 16POM + 50.71POH + 40.16PPL + 22.2PPM + 19.34PPH + 3RPML + 5.32RPMM + 10.72RPMH ≤ 120
(11) July: 3PML + 5.32PMM + 10.72PMH + 7.26PBL + 20PBM + 8.68PBH + 19.44PTL + 27.16PTM + 20.44PTH + 46POL + 20POM + 25.84POH + 40.16PPL + 22.2PPM + 12PPH + 3RPML + 5.32RPMM + 10.72RPMH ≤ 124
(12) August: 10.72PMH + 1.815PBL + 0.88PBH + 18.44PTL + 27.16PTM + 20.44PTH + 46POL + 100POM + 100POH + 64 PPL + 25PPM + 25PPH + 10.72RPMH ≤ 124
(13) September: 18PML + 23PMM + 26.5PMH + 32PBL + 19PBM + 16PBH + 99.22PTL + 267.58PTM + 263.85PTH + 18RPML + 23RPMM + 26.5RPMH ≤ 120

[8] X = number of miles from household to market; will be varied.

Transport Transfer Rows:

(14) Maize: 8000PML + 11600PMM + 15400PMH + 8000RPML + 11600RPMM + 15400RPMH – 1TM = 0
(15) Beans: 2400PBL + 2000PBM + 4500PBH – 1TB = 0
(16) Tomato: 85000PTL + 101168PTM + 122500PTH – 1TT = 0
(17) Onion: 45000POL + 165000POM + 52500POH – 1TO = 0
(18) Potato: 24000PPL + 45000PPM + 56000PPH – 1TP = 0

Food Security Constraints:

(19) Maize: 1PML + 1PMM + 1PMH + 1RPML + 1RPMM + 1RPMH + 1CM ≥ 990
(20) Beans: 1PBL + 1PBM + 1PBH + 1CM ≥ 742.5

Rotation Constraints:

(21) Tomato and Maize: 1PML + 1PMM + 1PMH – 1PTL – 1PTM – 1PTH = 0
(22) Potato and Onion: 1POL + 1 POM + 1POH – 1PPL – 1PPM – 1PPH = 0
(23) Maize and Beans: 1PBL + 1PBM + 1PBH – 1RPML – 1RPMM – 1RPMH = 0

Table B.1: Linear Programming Baseline Model Tableau

	PML	PMM	PMH	PBL	PBM	PBH	PTL	PTM	PTH	POL	POM	POH	PPL	PPM	PPH	RPML	RPMM	RPMH
Maximize	-519.95	-1116.14	-1470.97	-392.16	-382.43	-1128.64	-3762.8	-10841.71	-9753.42	-5161.53	-5538.15	-6262.39	-3491.22	-3634.04	-5070.17	-519.95	-1116.14	-1470.97
Maize Yield Transfer	8000	11600	15400	0	0	0	0	0	0	0	0	0	0	0	0	8000	11600	15400
Beans Yield Transfer	0	0	0	2400	2000	4500	0	0	0	0	0	0	0	0	0	0	0	0
Tomato Yield Transfer	0	0	0	0	0	0	85000	101168	122500	0	0	0	0	0	0	0	0	0
Onion Yield Transfer	0	0	0	0	0	0	0	0	0	45000	165000	52500	0	0	0	0	0	0
Potato Yield Transfer	0	0	0	0	0	0	0	0	0	0	0	0	24000	45000	56000	0	0	0
Land	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
April Labor	0	0	8.64	2	1	0	0	288	0	120	7	17	36	48.39	17.99	0	0	8.64
May Labor	25	13.32	23.32	17.26	28	14.43	34.44	109.83	64.94	46	18	136.38	56.16	30.2	28.67	25	13.32	23.32
June Labor	3	5.32	10.72	9.26	20	11.28	18.44	29.83	24.94	46	16	50.71	40.16	22.2	19.34	3	5.32	10.72
July Labor	3	5.32	10.72	7.26	20	8.68	19.44	27.16	20.44	46	20	25.84	40.16	22.2	12	3	5.32	10.72
August Labor	0	0	10.72	1.815	0	0.88	18.44	27.16	20.44	40	100	100	64	25	25	0	0	10.72
September Labor	18	23	26.5	32	19	16	99.22	267.58	263.85	0	0	0	0	0	0	18	23	26.5
Maize Transport Transfer	8000	11600	15400	0	0	0	0	0	0	0	0	0	0	0	0	8000	11600	15400
Beans Transport Transfer	0	0	0	2400	2000	4500	0	0	0	0	0	0	0	0	0	0	0	0
Tomato Transport Transfer	0	0	0	0	0	0	85000	101168	122500	0	0	0	0	0	0	0	0	0
Onion Transport Transfer	0	0	0	0	0	0	0	0	0	45000	165000	52500	0	0	0	0	0	0
Potato Transport Transfer	0	0	0	0	0	0	0	0	0	0	0	0	24000	45000	56000	0	0	0
Maize Food Security	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Beans Food Security	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Rotation T:M	1	1	1	0	0	0	-1	-1	-1	0	0	0	0	0	0	0	0	0
Rotation P:O	0	0	0	0	0	0	0	0	0	1	1	1	-1	-1	-1	0	0	0
Rotation M:B	0	0	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	1	1	1

	CM	CB	SM	SB	ST	SO	SP	TM	TB	TT	TO	TP		RHS
Maximize	0	0	0.26	0.3	0.22	0.18	0.16	-0.0130645	-0.0130645	-0.03	-0.025	-0.02		
Maize Yield Transfer	-1	0	-1	0	0	0	0	0	0	0	0	0	=	0
Beans Yield Transfer	0	-1	0	-1	0	0	0	0	0	0	0	0	=	0
Tomato Yield Transfer	0	0	0	0	-1	0	0	0	0	0	0	0	=	0
Onion Yield Transfer	0	0	0	0	0	-1	0	0	0	0	0	0	=	0
Potato Yield Transfer	0	0	0	0	0	0	-1	0	0	0	0	0	=	0
Land	0	0	0	0	0	0	0	0	0	0	0	0	<=	7.15
April Labor	0	0	0	0	0	0	0	0	0	0	0	0	<=	120
May Labor	0	0	0	0	0	0	0	0	0	0	0	0	<=	124
June Labor	0	0	0	0	0	0	0	0	0	0	0	0	<=	120
July Labor	0	0	0	0	0	0	0	0	0	0	0	0	<=	124
August Labor	0	0	0	0	0	0	0	0	0	0	0	0	<=	124
September Labor	0	0	0	0	0	0	0	0	0	0	0	0	<=	120
Maize Transport Transfer	0	0	0	0	0	0	0	-1	0	0	0	0	=	0
Beans Transport Transfer	0	0	0	0	0	0	0	0	-1	0	0	0	=	0
Tomato Transport Transfer	0	0	0	0	0	0	0	0	0	-1	0	0	=	0
Onion Transport Transfer	0	0	0	0	0	0	0	0	0	0	-1	0	=	0
Potato Transport Transfer	0	0	0	0	0	0	0	0	0	0	0	-1	=	0
Maize Food Security	1	0	0	0	0	0	0	0	0	0	0	0	>=	990
Beans Food Security	0	1	0	0	0	0	0	0	0	0	0	0	>=	742.5
Rotation T:M	0	0	0	0	0	0	0	0	0	0	0	0	=	0
Rotation P:O	0	0	0	0	0	0	0	0	0	0	0	0	=	0
Rotation M:B	0	0	0	0	0	0	0	0	0	0	0	0	=	0

Appendix C: Relationship between Profit and Distance

Figure C.1: Impact of Distance to Market on Total Profit